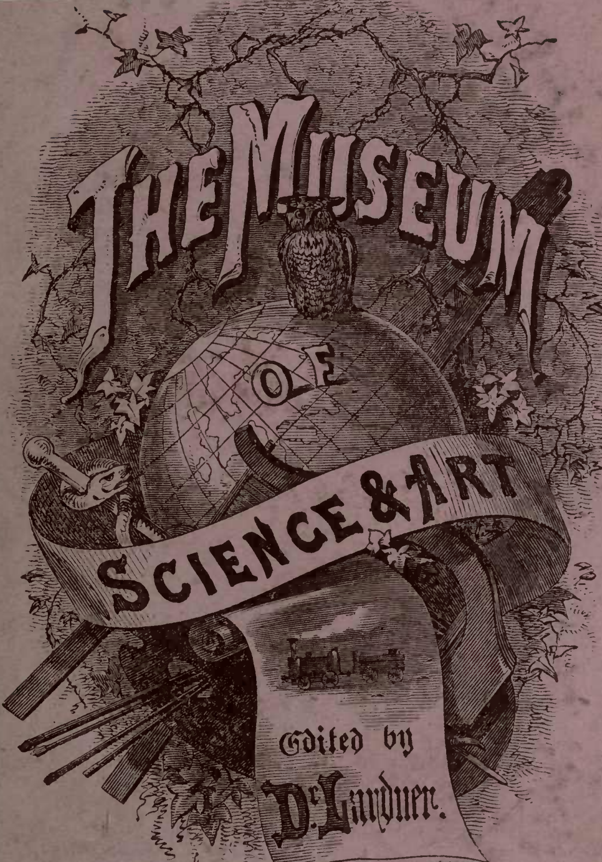

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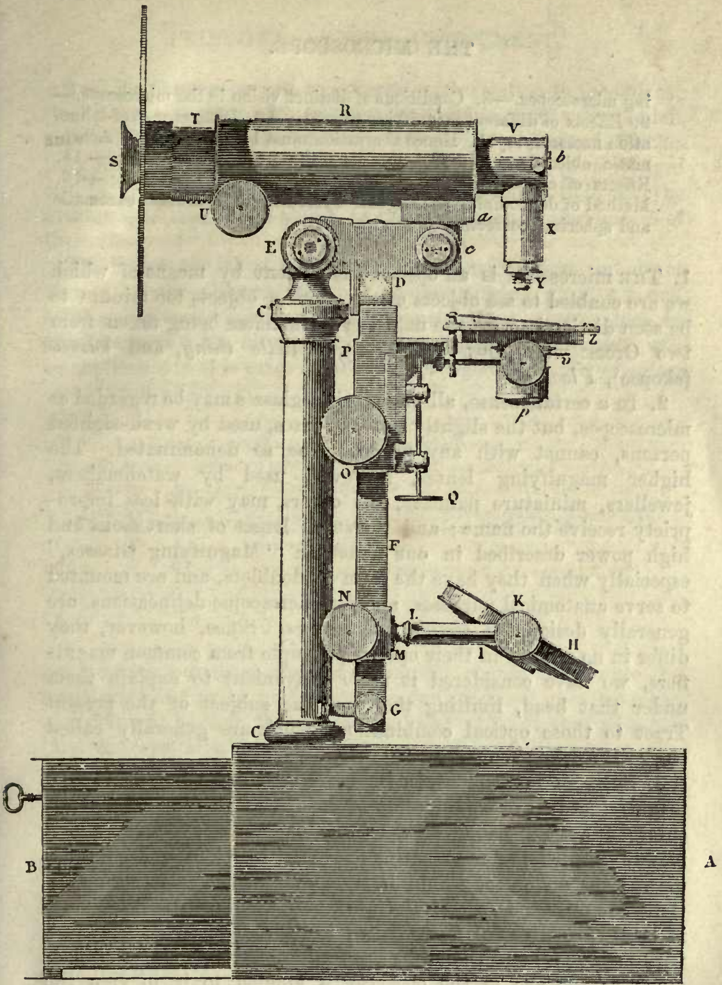


Fig. 37.—CHEVALIER'S UNIVERSAL MICROSCOPE.

THE MICROSCOPE.

CHAPTER I.

1. Origin of the term.—2. Simple microscopes are magnifying glasses.—3. Compound microscope.—4. Object-glass and eye-glass.—5. General description of the instrument.—6. Uses of the field-glass.—7. Reflect-

ing microscopes.—8. Conditions of distinct vision in the microscope.—9. Effects of different magnifying powers.—10. Distinctness of delineation necessary.—11. Hence aberration must be effaced.—12. Achromatic object-lenses.—13. Sufficient illumination necessary.—14. Effects of angular aperture.—15. Experiments of Dr. Goring.—16. Method of determining the angular aperture.—17. Mutual chromatic and spherical correction of the lenses.

1. THE microscope is an optical instrument by means of which we are enabled to see objects or the parts of objects too minute to be seen distinctly with the naked eye, the name being taken from two Greek words, μικρὸν (mikron), *a little thing*, and σκοπέω (skopeo), *I look at.*

2. In a certain sense, all magnifying-glasses may be regarded as microscopes, but the slightly convex lenses, used by weak-sighted persons, cannot with any propriety be so denominated. The higher magnifying lenses, however, used by watchmakers, jewellers, miniature painters, and others, may with less impropriety receive the name; and the small lenses of short focus and high power described in our Tract on "Magnifying Glasses," especially when they have the form of doublets, and are mounted to serve anatomical purposes, and for microscopic delineations, are generally designated *simple microscopes.* Since, however, they differ in no respect in their optical principle from common magnifiers, we have considered it more convenient to explain them under that head, limiting therefore the subject of the present Tract to those optical combinations which are generally called COMPOUND MICROSCOPES.

3. Such an instrument, in its most simple form, consists of a magnifying lens or combination of lenses, by means of which an enlarged optical image of a minute object is produced, and a magnifying lens, or combination of lenses, by which such image is viewed, as an object would be by a simple microscope.

4. The former is called the OBJECT-GLASS, or OBJECTIVE, since it is always directed immediately to the object, which is placed very near to it; and the latter the EYE-GLASS, or EYE-PIECE, inasmuch as the eye of the observer is applied to it, to view the magnified image of the object.

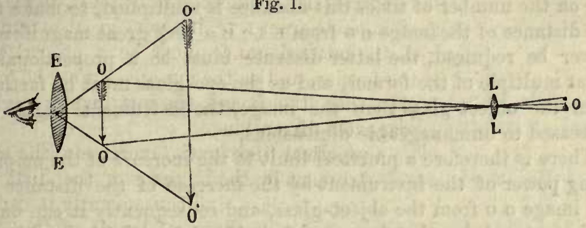
5. Such a combination will be more clearly understood by reference to fig. 1, where *o* is the object, L L the object-glass, and E E the eye-glass.

The object-glass, L L, is a lens of very short focal length, and the object *o* is placed in its axis, a very little beyond its focus. According to what has been explained in our Tract upon "Optical Images," 31 *et seq.* an image O O, of *o*, will be produced at a distance from the object-glass L L, much greater than the distance of

o from it: this image will be inverted with relation to the object; its top corresponding with the bottom, and its right with the left side of the object, and *vice versâ:* the linear magnitude of this image will be greater than that of the object, in the proportion of O L to *o* L, and consequently its superficial magnitude will be greater than that of the object, in the proportion of the squares of these lines.

The image O O, thus formed, may be considered as an object viewed by the observer, through the magnifying glass E E, and all that has been explained, relating to the effect of such a lens, in our Tracts on "Magnifying Glasses" and "Optical Images," will be applicable in this case. The observer will adjust the eye-glass

Fig. 1.



E E, at such a distance from O O, as will enable him to see the image most distinctly, and the impression produced upon his sense of vision will be that the image he looks at, is at that distance from his eye, at which he would see such an object most distinctly without the interposition of any magnifying lens; let this distance be that of a similar image O′ O′, and the impression will be that the object he beholds has the magnitude O′ O′.

The distance of most distinct vision with the naked eye, and the distance from the image at which the eye-glass must be placed to produce distinct vision, both vary for different eyes, but they vary almost exactly in the same proportion, so that the magnifying effect of the eye-glass upon the image O O, will be the same, whether the observer be long-sighted or short-sighted; in estimating the magnifying power, therefore, of such a combination, we may consider, in all cases, the distance of the eye-glass E E from the image O O, to be equal to its focal length, and the distance of O′ O′ from the eye-glass, to be 10 inches. (See "Magnifying Glasses," 8.)

To estimate the entire amplifying effect of such a microscope, we have only to multiply the magnifying power of the object-glass by that of the eye-glass; thus, for example, if the distance of the image O O from the object-glass be 10 times as great as the

distance of the object from it, the linear dimensions of the image O O will be 10 times greater than those of the object; and if the focal length of the eye-glass be $\frac{1}{2}$ an inch, the distance of most distinct vision being 10 inches, the linear dimensions of O′ O′ will be 20 times those of O O, and therefore 200 times those of the object; the linear magnifying power would in that case be 200, and consequently the superficial magnifying power 40000.

It would seem therefore, theoretically, that there would be no limit to the magnifying power of such a combination; practically, however, there are circumstances which do impose a limit upon it. It must be remembered that the object must always be placed at a distance from the object-glass, greater than the focal length of the latter, the magnifying power of the object-glass depending on the number of times this distance is multiplied, to make up the distance of the image O O from L L; if a very great magnifying power be required, the latter distance must be a proportionally great multiple of the former, and as the eye-glass must be farther from the object-glass than the image, the instrument might be increased to unmanageable dimensions.

There is therefore a practical limit to the increase of the amplifying power of the instrument by the increase of the distance of the image O O from the object-glass, and consequently it can only be augmented by the decrease of the focal length of the object-glass, combined with a corresponding decrease of that of the eye-glass. By such means, the distance of *o* from L L will be contained a great number of times in O L, while the latter has not objectionable length, and the distance of the eye-glass from the image O O will be contained a great number of times in the distance of most distinct vision.

The eye and object glasses are usually mounted at the distance of 10 or 12 inches asunder, adjustments nevertheless being provided, by which their mutual distance can be varied within certain limits.

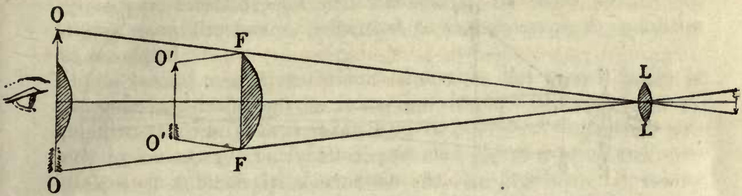
6. A convex lens is generally interposed between the object-glass and eye-glass, which receiving the rays diverging from the former, before they form an image, has the effect of contracting the dimensions of the image, and at the same time increasing its brightness. The effect of such an intermediate lens will be understood by reference to fig. 2, where F F is the intermediate lens. If this lens F F were not interposed, the object-glass L L would form an image of the object *o* at O O; but this image being too large to be seen at once with any eye-glass, a certain portion of its central part would only be visible. The lens F F, however, receiving the rays before they arrive at the image O O, gives them increased convergence, and causes them to produce a smaller

image o′ o′, at a less distance from the object-glass L L. The dimensions of this image are so small, that every part of it can be seen at once with the eye-glass.

The portion of the image which can be seen at once with the eye-glass, is called the FIELD OF VIEW of the microscope.

It is evident from what has been stated, that the effect of the

Fig. 2.



lens F F is to increase the field of view, since by its means the entire image of the object can be seen, while without its interposition the central parts only would be visible.

The lens F F has, from this circumstance, been called the FIELD-LENS.

But the increase of the field is not the only effect of this arrangement.

The light which would have been diffused over the surface of the larger image o o, is now collected upon that of the smaller image o′ o′; and the brightness, therefore, will be increased in the same proportion as the surface of o o is greater than the surface of o′ o′, that is, in the proportion of the square of o o to the square of o′ o′.

Another effect of the field-lens is to diminish the length of the microscope, for the eye-glass, instead of being placed at its focal distance from o o, is now placed at the same distance from o′ o′.

7. In this brief exposition of the general principle of the microscope, the image, which is the immediate subject of observation, is supposed to be produced by a convex lens; such an image, however, may also be produced by a concave reflector, and being so produced may be viewed with an eye-glass, exactly in the same manner as when produced by a convex lens.

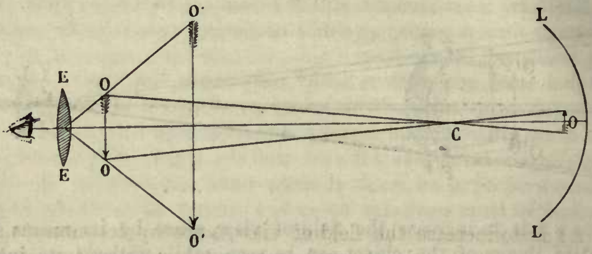
Microscopes have accordingly been constructed upon this principle, and are distinguished as REFLECTING MICROSCOPES; those in which the image is produced by a lens being called REFRACTING MICROSCOPES.

The principle of a reflecting microscope will be understood by reference to fig. 3, where L L is the concave reflector, of which C is the centre; the object *o* is placed towards the reflector, at a

distance from C greater than half the radius, and an inverted image of it is formed at O O, which, as in the case of the refracting microscope, is looked at with an eye-glass E E.

The great improvements which have taken place within the last twenty years in the formation of the object-glasses of refracting microscopes, have rendered these so very superior to reflecting

Fig. 3.



microscopes, that the latter class of instruments having fallen so completely into disuse, it will not be necessary here to notice them further.

In what has been explained, the general principle only of the microscope has been developed; many important circumstances of detail upon which its efficiency mainly depends must now be noticed.

8. The conditions which render the vision of an object with the microscope clear and distinct are essentially the same as those which determine the clearness and distinctness of our perception of an object with the naked eye. It will be found, by reference to our Tract upon "the Eye," that these conditions are three:—

1. That the visual angle should be sufficiently large;

2. That the outlines and lineaments of the object should be sufficiently distinct; and

3. That the object should be sufficiently illuminated.

It is evident that if any one of these conditions fail to be fulfilled, our visual perception of the object will be defective. If the object, for example, be exceedingly minute, though it be perfectly delineated and strongly illuminated, it will be either altogether invisible, or will appear as a mere speck.

If its outlines and lineaments be ill-defined, as when a tree or other object is seen through a mist, our perception of it will also be defective; and in fine, though it have sufficient magnitude and be perfectly delineated, we may fail to see it distinctly for want of sufficient light upon it, as when we look at objects towards the close of twilight.

The object which is submitted to our sense of vision with the microscope, being the optical image produced by the object-glass, our perception of it can only be clear and distinct, provided the three conditions above stated are fulfilled, that is, provided it be viewed under a sufficient visual angle, that its outline and lineaments be shown with perfect distinctness, and that it be sufficiently illuminated.

The conditions, therefore, upon which the efficiency of the microscope must depend will necessarily be those which will confer upon the image, submitted to the observer, the qualities above stated.

The optical conditions which determine the visual angle or apparent magnitude of the image, as viewed with the eye-glass, have been already explained; and it is evident that these conditions can always be fulfilled, provided object-glasses and eye-glasses of sufficiently short focus can be produced. Speaking generally, the magnifying power of the object-glass will be limited by the proportion which the length of the microscope will bear to its focal length; and the magnifying power of the eye-glass will be limited only by its power of approaching sufficiently close to the image, without too much contracting the field of view.

If the purpose of the observer were merely to see the object as a whole, so as to obtain a perfectly accurate notion of its outlines, a moderate magnifying power would, in general, suffice. But in most microscopic researches it is desired to ascertain, not merely the general outlines of the object, but the far more minute lineaments of its structure; and to render these visible in the minuter class of objects, amplifying powers of a very high order are indispensable.

9. The powers, indeed, which exhibit to the observer the general outline of an object, are rarely sufficient to show the minute lineaments of its structure. To perceive the general outline, it is necessary that the entire object should be included at once within the field of view, and this could not be the case, if the magnifying power exceeded a moderate limit. The power, on the other hand, which is sufficiently great to show the most minute parts of the structure, would necessarily be so great that a very small part only of the entire object would be comprised in the field of view.

From these circumstances it will be readily understood, that each class of powers have their peculiar uses, neither superseding the other; when we desire to observe the general form of a microscopic object, we must view it with a low power. When we desire, on the other hand, to examine its parts, and if, for example, it be an animalcule, to observe it member by member, and organ

by organ, we must call to our aid the higher class of power. In fine, a complete microscopic analysis of an individual object will require that it should be viewed successively with a series of gradually increasing powers.

10. But magnifying powers, to whatever extent they may be carried, will be of no avail if the image produced by the object-glass be not perfectly distinct and well defined; and it will be evident upon the slightest consideration, that any minute imperfections which may exist in its delineation, will be rendered more and more glaring and intolerable, the higher the magnifying power under which it is viewed.

With a common magnifying glass, or simple microscope, we view the object itself, and are subject to no other optical imperfections in our perception of it, than such as may arise from the imperfection of the lenses through which we view it; and since with such instruments the magnifying power can never be considerable, small defects of delineation are never perceptible. It is quite otherwise, however, with the class of instruments now under consideration, where magnifying powers, from 1000 to 2000 of the linear dimensions, are often brought into play.

These circumstances render it indispensable that the image of the object produced by the object-glass, and viewed through the eye-glass, should have the utmost attainable distinctness of delineation; not only as regards its outline, but also as respects the most minute details of its structure and colouring.

11. Now the solution of this problem, presented to scientific and practical men the most enormous difficulties; difficulties so great as to have been regarded, by some of the highest scientific authorities of the last half-century, as absolutely insurmountable. Happily, nevertheless, the problem has been solved; and without disparagement to the great lights of science, we must admit that its solution has been mainly the work of practical opticians. It is true that the general principles upon which the form and material of the lenses depend, were the result of profound mathematical research, but these principles were established and well understood at the moment when the practical solution of the problem was, by scientific authorities themselves, pronounced to be all but impossible. Opticians, stimulated by microscopists and amateurs, then applied themselves to the work, and by a long series of laborious and costly trials, attended with many and most discouraging failures, at length arrived at the production of optical combinations, which have rendered the microscope one of the most perfect instruments of philosophic research, and one, to the increasing powers of which, we can scarcely see how any limit can be assigned.

To appreciate the circumstances in which these great difficulties have consisted, it will be necessary that the reader should revert to our Tract upon "Optical Images," 39 *et seq.* It is there shown, that when an object is placed before a convex lens, the image of it which is produced, is not in any case a faithful copy of the object. In the first place, each portion of the lens, proceeding from its centre to its borders, produces a separate image; this series of images, being ranged at different distances from the lens: when these images are looked at, as they would be, for example, with the eye-glass of the microscope, they are seen projected one upon another, and being slightly different in their magnitudes, a confusion of outline and lineaments ensues, so that the object appears as though it were viewed through a mist.

This sort of indistinctness, called *spherical aberration*, has been fully explained in our Tract upon "Optical Images," and the general principles, by which its effects may be more or less mitigated, have been there explained.

It has been in the diminution, if not entire extinction, of this cause of indistinctness, by the happy adaptation of the curvatures of the lenticular surfaces entering into the optical combinations which form the microscope, that the address and genius of the practical opticians has been chiefly manifested; and if it cannot be stated, with strict truth, that all the effects of spherical aberration have been effaced in the best instruments now placed at the disposition of the observer, it may, at all events, be safely affirmed, that they exist in so small a degree as to offer no serious impediment to his researches.

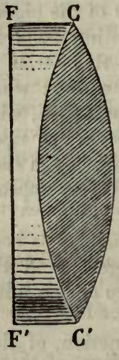
But independently of this source of indistinctness, there is another which has also been fully explained in our Tract upon "Optical Images," 39.

Light is a compound principle, consisting of several elements, differing in colour and also in refrangibility, the consequence of which is, that when an object is placed before a convex lens, it is not one image which is formed of it, but a series of images, varying in colour, from a violet or blue, through all the tints of the rainbow, to a red; these images are placed at slightly different distances from the lens, and when viewed through the eye-glass, would be projected one upon the other, and being of slightly different magnitudes, the consequence of such projection would be, that their outlines, and those of all their parts, would be more or less fringed with iridescent colours, an effect which, it is needless to say, would destroy the distinctness of the lineaments.

12. The principle upon which this chromatic aberration is counteracted, has been fully explained in our Tract upon "Optical

Images." It follows from what is there stated, that all confusion produced by this cause, can be removed by substituting for simple convex lenses, compound ones, consisting of a double convex lens of crown-glass C C′, fig. 4, cemented to a plano-concave lens of flint glass.

Fig. 4.



The image produced by such a combination, will be distinct and free from colour, provided that certain conditions be observed in the curvatures given to its component lenses.

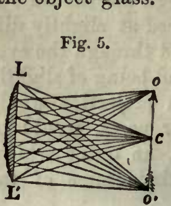
13. Assuming then, that by such combinations the image presented to the eye-glass is a faithful reproduction of the object, in its proper colours, perfectly distinct in all its lineaments, and sufficiently amplified, there is still one remaining condition for distinct vision, which is, that this image should be sufficiently bright. It will, therefore, be necessary here, to examine the conditions on which its brightness, or illumination, depends.

In the first place it is very evident that, other things being the same, the illumination of the image will be proportionate to that of the object, and in the inverse proportion of its superficial amplification; for the light which is transmitted from the object, being diffused over the surface of the image, will be necessarily more feeble as the superficial magnitude of the image is greater. The higher the magnifying power used, therefore, the greater is the necessity that the object should be intensely illuminated.

But the brightness of the image depends not only on the intensity of the illumination of the object, but also on the proportion of the light emanating from each point of the object, which arrives at the corresponding point of the image; and this, as we shall now show, will depend conjointly on the linear opening, or available diameter of the object-glass, and the distance of the object from it.

To make this more plain, let o o', fig. 5, be the object, and L L′ the object-glass. We are to consider that each point of the object is a centre, from which rays emanate towards the object-glass; thus, for example, rays issuing from the point c, form a cone, of which the object-glass is the base, and of which c is the vertex; supposing all these rays to pass through the object-glass, and to be refracted by it, they will converge to the point of the image which corresponds to c.

Fig. 5.



In the same manner, the rays which diverge from any other point, such as o, likewise form a cone, of which

that point is the vertex, and the object-glass the base, and after passing through the lens, they will converge to the corresponding point of the object.

Thus it appears that each point of the image is illuminated by as many rays as are included within such a cone as we have here described; that is to say, one whose base is the object-glass, and whose vertex is on the object. But it is evident that the number of rays included in such a cone, depends exclusively upon the magnitude of its angle, that is the angle L *c* L′, formed by lines drawn from a point, *c*, upon the object.

14. This angle, which forms, therefore, an element of capital

Fig. 6.

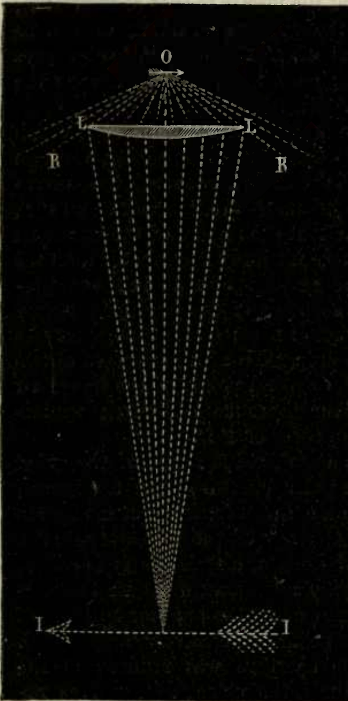
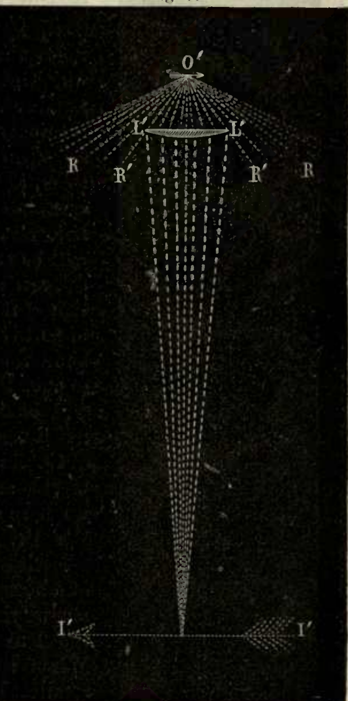


Fig. 7.



importance in the estimation of the efficiency of the microscope, is called the ANGULAR APERTURE of the object-glass.

The effect produced by the variation of the angular aperture of the object-glass, other things being the same, will be rendered

still more clearly intelligible by reference to figs. 6 and 7, where two lenses, L L and L′ L′, having equal focal lengths, are represented; the same object, O and O′, is placed at the same distances from them, and equal images of it, I I and I′ I′, are produced at equal distances from the lenses. The angular aperture of L L, being L O L, is greater than that of L′ L′, which is L′ O′ L′; and it is evident that a greater number of rays issuing from the object, will fall upon the lens L L, than upon L′ L′, in the proportion of the square of the angular aperture of the former to that of the latter; thus, if the angular aperture of L L be twice that of L′ L′, the number of rays which fall on L L will be four times the number which fall on L′ L′.

Fig. 8.

Supposing, then, that all the rays which fall upon each of the lenses, pass through them, and are made to converge upon corresponding points of the images I I and I′ I′, it is clear that each point of the image I I will be more intensely illuminated than the corresponding point of I′ I′, in the proportion of the square of the angular aperture of L L to that of L′ L′; and if these apertures be in the proportion above supposed of two to one, the several points of the image I I will be four times more intensely illuminated than those of I′ I′.

15. As a practical example of the effect of the angular aperture upon the image, we here give seven drawings made by the late Dr. Goring, of the appearance of a particle of dust, or a scale, as it is called, of a butterfly's wing, viewed with the same magnifying power, the angular aperture of the lens being successively augmented. When the aperture was reduced to the smallest limit, the object appeared as represented at A, fig. 8; when the aperture was increased in the proportion of 2 to 3, the object assumed the appearance represented at B, and, in short, by successively increasing the aperture, it assumed the appearances shown in C, D, E, F, and G. It will be

evident, therefore, that by the mere effect of this increased illumination, the lineaments showing the structure of the object, which were altogether imperceptible in C and D, began to be developed but very imperfectly in E, were more visible in F, and became quite distinct in G.

The great and manifest importance, therefore, of the angle of aperture to the efficiency of the microscope, renders it indispensable that easy and practicable means should always be attainable for determining it. If the distance of the object from the object-glass, and the virtual opening or diameter of the object-glass could be always exactly measured; and if all the rays which fall on the object-glass could be assumed to pass through it, and to converge upon the image, then the angular aperture would be an element of very easy calculation. But it is not practicable to obtain these data, and it cannot be assumed that all the rays which are incident upon the object-glass will pass through it, and be made to converge upon the image.

16. Instead, therefore, of calculating the angular aperture in this manner, it is determined by immediate experiment.

The greatest angle of aperture of which a given lens is capable, will be found by determining the greatest obliquity with which it is possible for rays to fall upon the object-glass, so as to be refracted by it to the eye-glass. The following method of ascertaining this, for any given object-glass, was contrived and practised by Mr. Pritchard, at an early epoch in the progress of the improvement of the microscope, when the importance of the angular aperture was demonstrated by that eminent artist and Dr. Goring. The same method, with but little modification, is that still practised by opticians.

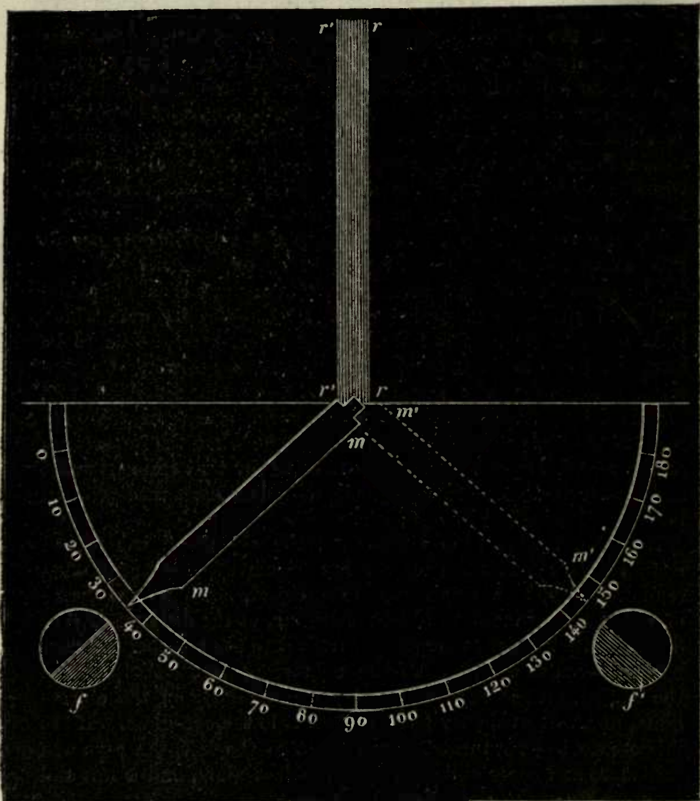
Let *m m*, fig. 9, be the microscope, the object end being fixed upon a pivot, so that the eye end can be moved over a graduated semicircle. Let a small luminous object, such as the flame of a candle, be placed in the direction *r r*, at the distance of 6 or 8 feet, so that the rays proceeding from it to the object-glass may be considered as parallel. If the microscope be directed towards the candle, all the rays will fall perpendicularly on the object-glass, and will evidently pass through it to the eye-glass. If the microscope be then turned on the pivot to the left, the rays will fall more and more obliquely on the object-glass, and a less and less number of them will pass to the eye-glass.

When such a position as *m m* is given to the microscope, those rays only which fall upon the border of the object-glass upon the right of the observer, will arrive at the eye-glass, and the field of view will then appear, as shown at *f*, half illuminated and half dark. If the microscope be moved beyond this position, the field

will be entirely dark, no rays being transmitted to the eye-glass.

If the microscope, on the contrary, be moved to the other side of the graduated semicircle, the same appearances will be produced, and when it assumes the position *m′ m′*, the field will be again half illuminated, and beyond that point it will be dark.

Fig. 9.



The arc of the graduated semicircle, included between the two positions *m m* and *m′ m′*, will then be the measure of the angular aperture of the object-glass, since that arc will correspond with the greatest obliquity, at which rays diverging from the object to

the object-glass, can pass through the latter, so as to arrive at the eye-glass.

Such are then, generally, the means by which the three conditions of distinct vision with the microscope will be fulfilled. The second of these conditions, that which involves the complete correction of the chromatic aberration, will, however, require here some further development, since it involves circumstances which have demanded the greatest artistic skill on the part of the makers.

17. It has been shown in our Tract upon "Optical Images," 53 *et seq.*, that the chromatic aberration of lenses is corrected by combining together two lenses, one of flint and one of crown glass, which have different effects upon the separation of the coloured images, the curvatures of their surfaces being so related, the one to the other, that the separation which would be produced by either is exactly counteracted by an equal separation in a contrary direction by the other. If the curvatures, however, of the two lenses be not so related as to produce this exact compensation, they may either give a predominance to the effect of the one or the other, so as to produce chromatic aberrations of opposite kinds; the coloured images thus produced being ranged in a contrary order.

When a single convex lens is used, the most refrangible rays are brought to a focus, nearer to the lens than the least refrangible; and consequently the violet and blue images are formed nearer to the lens than the red and orange. This is called POSITIVE CHROMATIC ABERRATION.

If by combining two lenses of flint and crown glass this aberration be more than compensated, that is, if the blue and violet images are not merely brought to coincide with the red and orange ones, so as to render the lens achromatic, but made to interchange place with them, so that the red and orange shall be nearest to, and the blue and violet farthest from the lens, the chromatic aberration will be NEGATIVE.

The importance of this in the practical construction of the microscope will presently appear.

It must be remembered that the microscope consists of the object-glass, the field-glass, and the eye-glass, and that its efficiency depends not merely upon the fidelity of the image produced by the object-glass, but upon that which is seen by the observer looking through the eye-glass. This last must be an exact reproduction of the object in form and colour.

Now it is easy to show that if the object-glass be absolutely achromatic, the image seen by the observer through the eye-glass will not be so; for, in that case, the rays forming the image produced by the object-glass passing successively through the field-

glass and the eye-glass, neither of which are achromatic, the image viewed by the observer through the eye-glass must be affected by as much positive aberration as is due to the combination of the field-glass and the eye-glass.

This defect might, it is true, be remedied by making both the field-glass and eye-glass achromatic; but independently of other objections to such an expedient, it would be needlessly expensive; and the same purpose is attained in a much more simple manner, upon the principles of positive and negative chromatic aberrations, which have just been explained.

The method practised for this purpose may be briefly and generally explained thus: The field-glass and the eye-glass being simple convex lenses, produce positive chromatic aberration. The object-glass, on the other hand, being a compound lens, may be so constructed, according to what has been just explained, as to produce negative chromatic aberration.

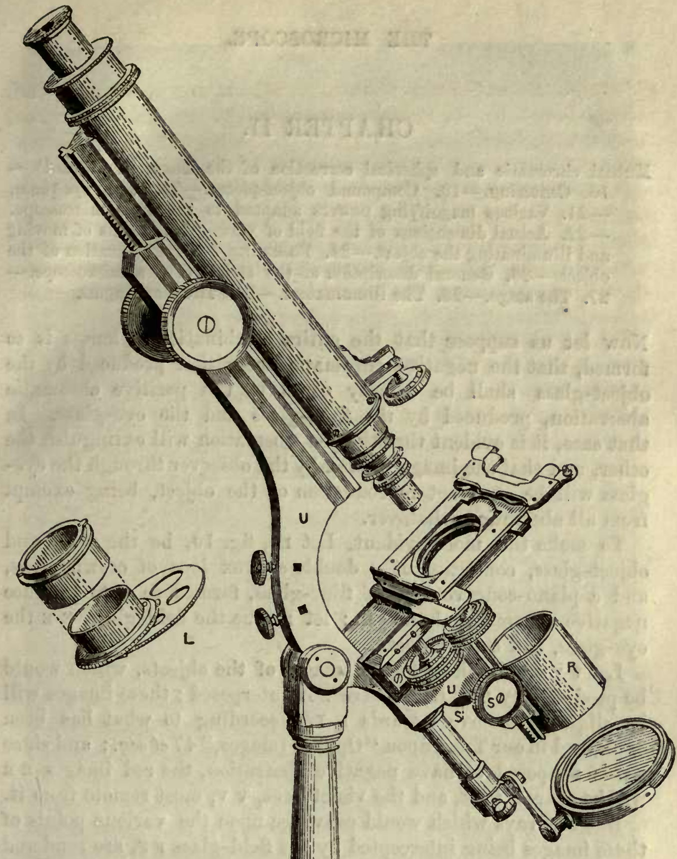


Fig. 42.—SMITH AND BECK'S MICROSCOPE.

THE MICROSCOPE.

CHAPTER II.

Mutual chromatic and spherical correction of the lenses (Continued).—18. Centering.—19. Compound object-pieces.—20. The eye-piece.—21. Various magnifying powers adapted to the same microscope.—22. Actual dimensions of the field of view.—23. Means of moving and illuminating the object.—24. Focussing.—25. Preparation of the object.—26. General description of the structure of a microscope.—27. The stage.—28. The illuminators.—29. The diaphragms.

Now let us suppose that the entire combination of lenses is so formed, that the negative chromatic aberration produced by the object-glass shall be exactly equal to the positive chromatic aberration, produced by the field-glass and the eye-glass. In that case, it is evident that the one aberration will extinguish the other, and that the image viewed by the observer through the eye-glass will be an exact reproduction of the object, being exempt from all aberration whatever.

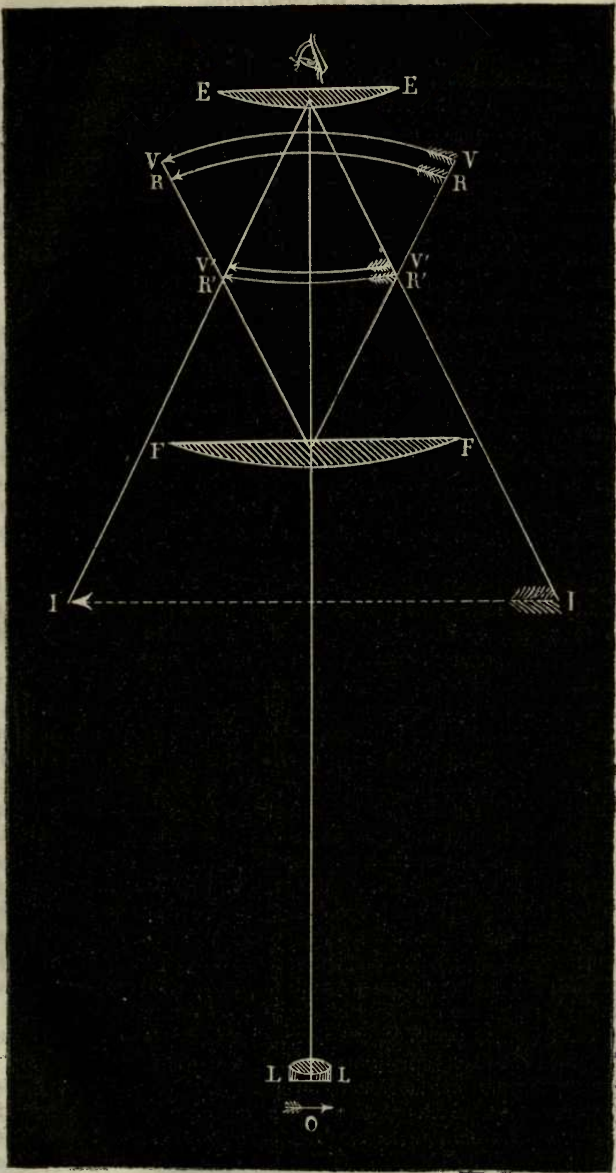
To make this more evident, Let LL, fig. 10, be the compound object-glass, consisting of a double convex lens of crown glass, and a plano-concave lens of flint-glass, formed so as to produce negative chromatic aberration; let F F be the field-glass, E E the eye-glass, and O the object.

Let V V R R be the coloured images of the objects, which would be produced by L L, if F F were not interposed; these images will be slightly concave towards L L, according to what has been explained in our Tract upon "Optical Images," 47 *et seq.*; and since L L is supposed to have negative aberration, the red images R R will be nearest to it, and the violet ones, V V, most remote from it.

But the rays which would converge upon the various points of these images being intercepted by the field-glass F F, are rendered more convergent by it, and the images are accordingly formed nearer to it. This lens, F F, also increases the convergence of the violet rays which are most refrangible, more than it increases that of the red rays which are least refrangible. The consequence of this is, that the violet and red images are brought closer together than they were, as shown in the figure; but still the violet images are more distant from F F than the red, so that the chromatic aberration of L L and F F conjointly is still negative, though less than the aberration of L L alone.

There is another effect produced by the lens F F which it is important to notice. The images produced by L L, which were slightly concave towards F F, are changed in their form, so as to be slightly concave towards E E. The cause of this change has been already explained in our Tract upon "Optical Images," 46.

Fig. 10.



In fine, then, the rays diverging from the images R′ R′ V′ V′, after passing through the eye-glass E E, have their divergence diminished, so as to diverge from more distant points, I I. The divergence of the violet rays, V′ V′, being most refrangible, is most diminished, and that of the red rays, R′ R′, being least refrangible, is least diminished. If their divergence were equally diminished, a series of coloured images would be formed at I I, the violet being nearer to, and the red farther from E E; but the divergence of the violet, which is already greater than the red, is just so much greater than the latter, that the difference of the effects of E E upon it is such as to bring the images together at I I.

Thus it appears, that the positive aberration of the eye-glass E E is exactly equal to the negative aberration of L L and F F taken conjointly, so that the one exactly neutralises the other, all the coloured images coalescing at I I, and producing an image altogether exempt from chromatic aberration.

There is another important effect produced by the eye-glass; the images R′ R′ V′ V′, which are slightly concave towards E E, are rendered straight and flat at I I; the principle upon which this change depends has been also explained in our Tract upon "Optical Images," 46.

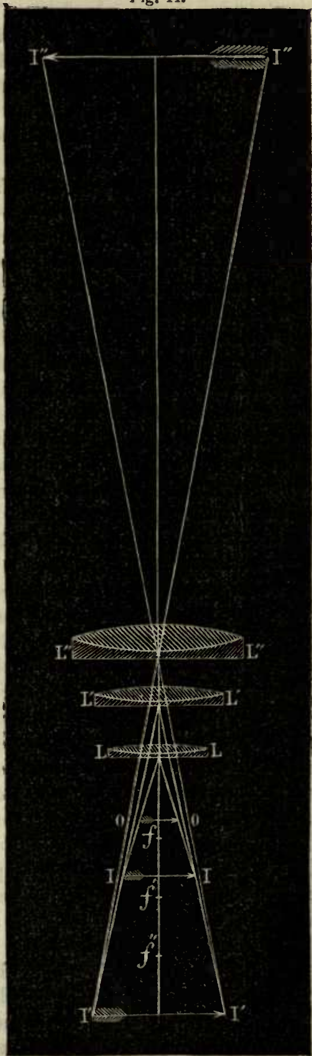
Thus, it appears that, by this masterly combination, a multiplicity of defects, chromatic, spherical, and distortive, are made, so to speak, to extinguish each other, and to give a result, practically speaking, exempt from all optical imperfection.

18. There is still another source of inaccuracy which, though it is more mechanical than optical, demands a passing notice. All the lenses composing the microscope require to be set in their respective tubes, so that their several axes shall be directed in the same straight line with the greatest mathematical precision. This is what is called CENTERING the lenses, and it is a process, in the case of microscopes, which demands the most masterly skill on the part of the workman. The slightest deviation from true centering would cause the images produced by the different lenses to be laterally displaced, one being thrown more or less to the right and the other to the left, or one upwards and the other downwards; and even though the aberrations should be perfectly effaced, the superposition of such displaced images would effectually destroy the efficiency of the instrument.

19. In what precedes, we have, to simplify the explanation, supposed the object-glass to consist of a single achromatic lens, a circumstance which never takes place except when very low powers are sufficient. A single lens, having a very high magnifying power, would have so short a focus and such great curvature, that it would be attended with great spherical aberration, inde-

pendently of other objections; great powers, therefore, have been obtained by combining several achromatic lenses in the same object-piece, so that the rays proceeding from the object are successively refracted by each of them, and the image submitted to the eye-glass is the result of the whole.

Fig. 11.



The optical effect of such a combination will be more clearly understood by reference to fig. 11, where L L, L′ L′, and L″ L″, represent a combination of three achromatic object-glasses. Let O O be the object, placed a little within the focus *f* of the lens L L. The image of O O, produced by L L, would then be an imaginary one in the position I I; (see Tract on "Optical Images," 35, *et seq.*). After passing through L L, the rays, therefore, fall upon L′ L′, as if they diverged from the several points of the image I I, which may, therefore, be considered as an object placed before the lens L′ L′. Let *f*′ be the focus of L′ L′; the image of I I produced by L′ L′ will therefore be imaginary, and will be at I′ I′; the rays after passing through L′ L′ will fall upon L″ L″, as if they diverged from the several points of I′ I′. This image I′ I′, therefore, may be considered as an object placed before the lens L″ L″. Let *f*″ be the focus of this lens; the image of I′ I′ produced by L″ L″ will then be I″ I″, and will be real; this will then, in fact, be the image transmitted to the eye-piece.

To render the diagram more easy of comprehension, we have not here attempted to represent the several distances in their proper proportions.

The compound lenses, of which object-pieces consist, are generally, as represented in the figure, plane on the sides presented towards the object. This is attended, among other advantages, with that of allowing a larger angle of aperture than could be obtained if the surface presented to the rays diverging from the object were convex.

The extreme rays diverging from each point of the object fall upon the surface of the object-glass with a greater and greater obliquity as they approach its borders, and since there is an obliquity so extreme that the chief part of the rays would not enter the glass at all, but would be reflected from it, the angle of aperture must necessarily be confined within such limits, that the rays falling from the borders of the lens will not be so oblique as to come under this condition. If the surface of the object-glass presented to the object were convex, it is evident that the rays diverging from an object at a given distance from it would fall upon its borders with greater obliquity than if it were plane, and, consequently, such an object-glass would allow of a less angle of aperture than a plano-convex one with its plane side towards the object.

Improvements have recently been made in object-glasses, by which angles of aperture have been obtained so great, as not to admit even of a plane surface being presented to the diverging pencil, and it has accordingly been found necessary, in such cases, to give the object-glasses the meniscus form (Optical Images, 25), the concave side being presented to the object. By this expedient angles of aperture have been obtained so great as 170°. If the surface of the object-glass presented to the object were plane, the extreme rays of the central pencils, with such an angle of aperture, would fall upon the surface of the lens with obliquities of not more than 5°, and the obliquities of the extreme rays of the lateral pencils would be even less. Under such circumstances, the chief part of the rays near the borders of the lens would be reflected, and, consequently, its virtual would be less than its apparent angle of aperture. It is questioned by some microscopists that even with the expedient of a concave external surface, a practically available angle of aperture so great as 170° can be obtained.

The three achromatic lenses here described being mounted, so that their axes shall be precisely in the same straight line, constitute what is generally called an OBJECT-GLASS, but which, perhaps, might with more convenience and propriety be denominated an OBJECT-PIECE.

The power of the object-pieces is usually indicated by the makers, by assigning their focal lengths; but as these object-pieces are composed of several lenses, having different focal lengths, it is necessary to explain what is meant by the focal length of the combination.

Let L be a single convex lens, and O the compound object-piece; suppose then, the same object placed successively at the same distance from L and O, and let L have such a convexity that it will produce an image, I, of the object equal to the image I′, which the object-piece, O, produces, and that the distance of this image, I, from the single lens L, is equal to the distance of the image I′ from the object-piece O. In that case, the single convex lens L, being, in fact, the optical equivalent of the compound object-piece O, its focal length is taken to be that of the object-piece O. Thus, for example, if the lens L, having a focal length of one inch, produce the same image of the same object similarly placed before it, as would the object-piece O, then the focal length of the object-piece O is said to be one inch.

In short, the single lens L, and its equivalent compound object-piece O, differ only in this, that the images produced by L are defaced more or less by aberration, from which the images produced by O are altogether exempt.

These object-pieces are sold by some makers so fixed that their component lenses are inseparable, the observer being unable to use any one of them as an object-glass without the others; other makers, however, mount them in such a manner that the first and second lenses, L L and L′ L′, may be unscrewed or drawn off, and the lens L″ L″ alone used as the object-glass; or L′ L′ may be screwed on, the two lenses L′ L′ and L″ L″ then making an object-piece of greater power; by this arrangement the observer obtains, without increased expense, three object-pieces of different powers.

After what has been said, however, of the exact manner in which the aberrations of the field and eye glasses are corrected and balanced by the contrary aberration of the object-piece, it will be easily understood, that the economy by which three powers are thus obtained, is gained at the expense of the efficiency of the instrument; for if the aberrations of the triple object-piece are so adjusted as exactly to balance those of the other lenses, that balance will no longer be maintained when the lens L L, and still less when the lens L′ L′, is removed. It is on this account that some makers, who are the most scrupulous as to the character of their instruments, refuse to supply separable object-pieces.

The imperfection, however, produced in this case by disturbing the balance of the aberrations is of less importance, inasmuch as by removing the lens L L, and still more by removing L′ L′, the

magnifying power is so considerably diminished, that the defects of the image produced by the unbalanced aberrations are very inconsiderable, and the observer is generally content to tolerate them on account of the great economy gained by the separation of the lenses, which supplies, without additional expense, three independent object-pieces.

Some of the foreign makers, less scrupulous in the exact adjustment of their optical combinations, make all the three lenses composing each triple object-piece exactly similar, unscrewing one from another, so as to enable the observer to use one, two, or three at pleasure. It is evident that, with such combinations, the aberrations can never be so exactly balanced as they are in the object-pieces above described; but in the instruments to which they are applied, powers exceeding 700 or 800 are almost never attempted, and the aberrations, though imperfectly compensated, are sufficiently so to prevent much injurious confusion in the images.

In the superior class of instruments, where magnifying power is pushed to so extreme a limit as 1500 or 2000, the most extreme precision in the balance of the aberrations must necessarily be realised, since the slightest imperfection so prodigiously magnified would become injuriously apparent.

The extreme degree of perfection, which has been attained in the best class of microscopes, may be imagined, when it is stated, that an object which is distinctly visible under a power of 1500 or 2000, when it is exposed to the object-glass uncovered, will be sensibly affected by aberration if a piece of glass, no more than the 100th of an inch in thickness, be laid upon it. Infinitesimally small as is the aberration produced by such a glass film, it is sufficient, when magnified by such a power, to be perceptible, and to impair in a very sensible manner the distinctness of the image.

As it has been found necessary, for the preservation of microscopic objects, to cover them with such thin films of glass, through which, consequently, they are viewed, adjustments are provided in microscopes with which the highest class of powers are supplied, by which even the small aberration due to these thin plates of glass thus covering the objects can be corrected. This is effected by mounting the lenses, which compose the triple object-piece, in such a manner that their mutual distances, one from another, can be varied within certain small limits, by motions imparted to them by fine screws. This change of mutual distance produces a small effect upon the aberrations, rendering their total results negative to an extent equal to the small amount of positive aberration produced by the thin glass which covers the object.

20. The eye-glass and the field-glass are both plano-convex

lenses, having their plane sides turned towards the eye; they are set in opposite ends of a brass tube, varying in length from two inches downwards, according to their focal lengths, the distance between them and, consequently, the length of the tube being always equal to half the sum of their focal lengths.

The higher the power of the eye-piece, and consequently the shorter the focal length of the eye-glass, the less will be the length of the tube in which they are set.

This tube is called the EYE-PIECE.

It will be apparent from what has been explained, that the magnifying power of the instrument will depend conjointly on those of the object-piece and eye-piece.

21. In the prosecution of microscopic researches, the use of very various magnifying powers is indispensable; the higher powers would be as useless for the larger class of objects, as the lower ones for the smaller. But even for the same object, a complete analysis cannot be accomplished without the successive application of low and high powers: by low powers the observer is presented with a comprehensive view of the entire form and outline of the object under examination, just as an aëronaut who ascends to a certain altitude in the atmosphere obtains a general view of the country, which would be altogether unattainable upon the level of the ground. By applying successively higher powers, as has been already explained, the smaller parts and minuter features of the object are gradually disclosed to view, just as the aëronaut, in gradually descending from his greatest altitude, obtains a view of objects which were first lost in the distance, but at the same time loses, by too great proximity, the general outline.

The microscope-makers, therefore, supply in all cases an assortment of powers, varying from 30 or 40 upwards; observations requiring powers under 40, being more conveniently made with simple microscopes. For this purpose it is usual, with the best instruments, to furnish six or eight object-pieces and three or four eye-pieces, each eye-piece being capable of being combined with each object-piece. The number of powers thus supplied will be equal to the product of the number of object-pieces, multiplied by the number of eye-pieces.

The powers, however, may still be further varied, by provisions for changing the distance between the object and eye-pieces, within certain limits. For this purpose, the tube of the instrument is sometimes divided into two, one of which moves within the other, like the tube of a telescope, the motion being produced by a fine rack and pinion: in this case the eye-piece is inserted in one of the tubes, and the object-piece in the other. By combining

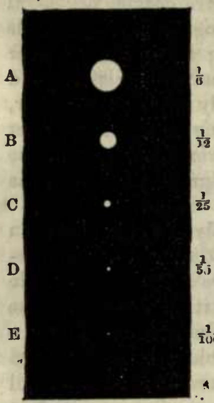
this provision with a proper assortment of object-pieces and eye-pieces, all possible gradations of power between the highest attainable, and the lowest which is applicable, can be obtained.

The actual magnitude of the space which can be presented at once to the view of the observer, will vary with the magnifying power; but in all cases it is extremely minute. Thus, with the lowest class of powers, where it is largest, it is a circular space, the diameter of which does not exceed the 8th or 10th of an inch; it follows, therefore, that no object, the extreme limits of whose linear magnitude exceed this, can be presented at once to the view of the observer. Such objects can only be seen in their ensemble, by means of less powerful magnifying glasses, or with the naked eye.

22. The field of view, with powers from 100 to 300, varies in diameter from the 15th to the 40th of an inch; from 300 to 500 it varies from the 40th to the 70th of an inch; and from 500 to 700 from the 70th to the 100th of an inch.

It will thus be understood, that even with the moderate power of 700, an object to be included wholly within the field of view, must have a magnitude such as may be included within a circle whose diameter does not exceed the 100th of an inch. These observations will be more clearly appreciated by reference to the annexed diagram, fig. 12, where A is a circle whose diameter is the 6th of an inch; B one whose diameter is the 12th of an inch; C the 25th, D the 50th, and E the 100th.

Fig. 12.



But when still higher powers are used, the actual dimensions of the entire space comprised within the field of view will be so very minute, that an object which would fill it, and still more, smaller objects included within it, would not only be altogether invisible to the naked eye, but would require considerable microscopic power to enable the observer to see them at all.

The actual dimensions of the field of view, which correspond to each magnifying power, vary more or less in different instruments. Those which I have given above, are taken from a microscope made by Charles Chevalier, which is in my possession. The difference however in this respect, between one instrument and another, is not considerable, and the above will serve as a fair illustration of the limits of the field of instruments in general.

The entire dimensions of the field of view therefore being so exceedingly minute, it will be easily understood that some difficulty will attend the process by which a small object, or any particular part of an object, can be brought within it: thus, with a moderate power of 500, the entire diameter of the field being no more than the 70th of an inch, a displacement of the object to that extent, or more, would throw it altogether out of view. If therefore the object, or whatever supports it, be moved by the fingers, the sensibility of the touch must be such as to be capable of producing a displacement thus minute.

If the object be greater in its entire dimensions than the field of view,—a circumstance which most frequently happens,—a part only of it can be exhibited at once to the observer; and to enable him to take a survey of it, it would be necessary to impart to it, or to whatever supports it, such a motion as would make it pass across the field of view, as a diorama passes before the spectators, disclosing in slow succession all its parts, and leaving it to the power of the observer to arrest its progress at any desired moment, so as to retain any particular part under observation.

The impracticability of imparting a motion so slow and regular by the immediate application of the hand to the object, or its support, will be very apparent, when it is considered that while the entire object may not exceed a small fraction, say, for example, the 20th of an inch in diameter, the entire diameter of the field of view may be as much as 20 times less, so that only a 20th part of the diameter of the object would be in any given position comprised within it.

23. These and similar circumstances have rendered it necessary that the want of sufficient sensibility and delicacy of the touch in imparting motion to the object, shall be supplied by a special mechanism, by means of which the fingers are enabled to impart to the object an infinitely slower and more regular motion, than they could give it without such an expedient. The means by which this is accomplished will be presently explained.

We have seen that the intensity with which the microscopic image is illuminated depends on the angle of aperture, other things being the same; but however large that angle may be, when considerable magnifying power is used, it is necessary that the object itself should be much more intensely illuminated than it would be by merely exposing it to the light of day, or that of the most brilliant lamp. It is therefore necessary to provide expedients, by which a far more intense light can be thrown upon it.

24. The instrument is said to be in FOCUS when the observer is enabled to see with the eye-glass the magnified image of the

object with perfect distinctness; this will take place provided the mutual distances between the eye-piece, the object-piece, and the object are suitably adjusted; and this adjustment may be accomplished by moving any one of these three towards or from the other two, while these last remain fixed: thus, for example, if the object and the object-piece remain unmoved, the instrument may be brought into focus by moving the eye-piece to or from the object-piece. The rack and pinion, already described, which moves the tube in which the eye-piece is inserted, can accomplish this. This provision, however, is not made in all microscopes.

If the eye-piece and the object be fixed, the instrument may be brought into focus by moving the object-piece to or from the object. To effect this, it would be necessary that the object-piece should be inserted in a tube, moved by a rack and pinion, like that of the eye-piece.

In fine, if the object-piece and eye-piece be both fixed, the instrument may be brought into focus by moving the object, or whatever supports it, to or from the object-glass.

All these methods are resorted to in the different forms in which microscopes are mounted by different makers.

25. Since nearly all material substances, when reduced to an extreme degree of tenuity, are more or less translucent, and since almost all microscopic objects have that degree of tenuity by reason of their minuteness, it happens that nearly all of them are more or less translucent; and where in exceptional cases a certain degree of opacity is found, it is removed without interfering with its structure, by saturating the object with certain liquids, which increase its translucency, just as oil renders paper semi-transparent. The liquid which has been found most useful for this purpose, is one called CANADA BALSAM. When the object is saturated with this liquid, it is laid upon a slip of glass, about two inches long and half an inch wide, and is covered with a small piece of very thin glass, made expressly for this purpose, the thickness in some cases not exceeding the 100th of an inch. It is usual to envelope the oblong slip of glass, in the middle of which the object is thus mounted with paper gummed round it, a small circular hole being left uncovered on both sides of the glass, in the centre of which the object lies.

The slips of glass thus prepared, with the objects mounted upon them, are called *slides* or *sliders*; and the objects thus mounted are so placed, that the axis of the object-piece shall be directed upon that part of them which is submitted to observation, provisions being made to shift the position of the slider, so as to bring all parts of the object successively under observation. Further provisions are also made to throw a light upon the

object, by which it will be seen as an object is on painted glass.

Since, however, there are some few objects which cannot be rendered translucent, expedients must be provided, by which they can be illuminated upon that side of them which is presented to the microscope. It is often necessary, also, even in the case of translucent objects, that they should be viewed by means of light thrown upon that side of them which is turned to the object-glass.

26. These general observations being premised, we shall proceed to explain the method by which the optical part of the instrument is mounted, and the several accessories by which the object is supported, moved, and illuminated.

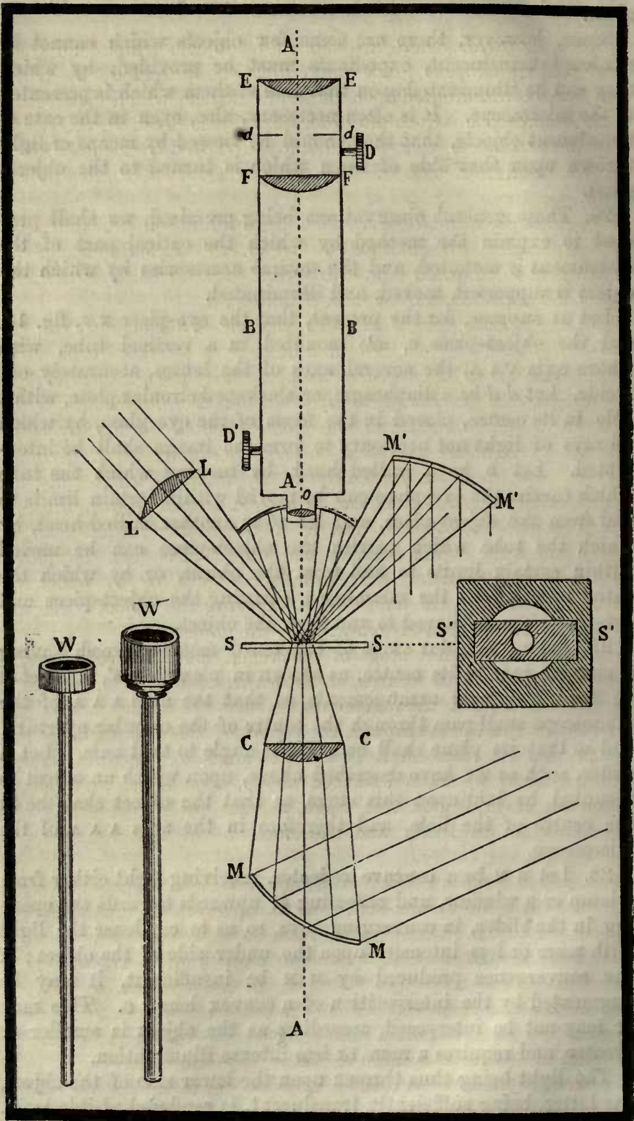
Let us suppose, for the present, that the eye-piece E F, fig. 13, and the object-piece *o*, are mounted in a vertical tube, with whose axis A A A, the several axes of the lenses, accurately coincide. Let *d d* be a diaphragm, or blackened circular plate, with a hole in its centre, placed in the focus of the eye-glass, by which all rays of light not necessary to form the image shall be intercepted. Let D be a milled head, by turning which the tube which carries the eye-piece can be moved within certain limits to and from the object-piece, and let D′ be another milled head, by which the tube which carries the object-piece can be moved within certain limits to and from the object, or by which the entire body B B of the microscope, carrying the object-piece and eye-piece, can be moved to and from the object.

27. Let S S be a flat stage of blackened metal or wood, having a circular hole in its centre, as shown in plan at S′ S′, and let it be fixed by proper arrangements, so that the axis A A A of the microscope shall pass through the centre of the circular aperture, and so that its plane shall be at right angle to that axis. Let a slider, such as we have described above, upon which an object is mounted, be laid upon this stage, so that the object shall be in the centre of the hole, and therefore in the axis A A A of the microscope.

28. Let M M be a concave reflector, receiving light either from a lamp or a window, and reflecting it upwards towards the opening in the slider, in converging rays, so as to condense the light with more or less intensity upon the under side of the object; if the convergence produced by M M be insufficient, it may be augmented by the interposition of a convex lens C C. This may or may not be interposed, according as the object is smaller or greater, and requires a more or less intense illumination.

The light being thus thrown upon the lower side of the object, the latter, being sufficiently translucent, is rendered visible by it.

Fig. 13.

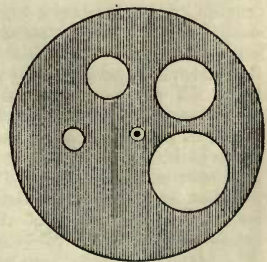


If the object be opaque, it may be illuminated from above by several expedients; being placed upon a blackened plate resting on the stage S S, light proceeding from a window or a lamp may be condensed upon it by a concave reflector M′ M′, or by a convex lens L L. These arrangements, however, are only applicable when the object is at such a distance from the object-piece that the light proceeding from M′ M′ or L L shall not be wholly or partially intercepted by the object-piece. This would always be the case, however, when very high powers are used, and when, consequently, the object must be brought very close to the object-piece. In that case, the object is supported upon a small piece of blackened cork, or in a dark cell of the form represented at W W; this support is placed in the centre of the opening of the stage, so as not to intercept any but the central rays reflected from M M; upon the end of the object-piece a concave reflector, having a hole in its centre, through which the object-piece passes, is fixed; the light proceeding from M M, and falling upon this reflector, is reflected by it, so as to converge upon the object, and thus to illuminate it.

A concave illuminator thus mounted is called, from its inventor, a *lieberkuhn*.

29. In the illumination of objects it is frequently necessary to limit, to a greater or less extent, the diameter of the pencil of light thrown from the reflector, M M, upon the object. Although this may partly be accomplished by varying the distance of the reflector from the object, or by the interposition of a convex lens, such expedients are not always the most convenient, and a much more ready and effectual method of attaining this end is supplied by providing below the stage, S S, a circular blackened disc, capable of being turned upon its centre in its own plane. This disc is pierced with a number of holes of different diameters, as shown in fig. 14, and it is so mounted, that the openings in it, by turning it round its centre, may be brought successively under the object. This is easily done by fixing the centre of this disc at a distance from the centre of the stage, equal to the distance between the centre of the disc and the centres of the holes made in it.

Fig. 14.



This appendage is called the *disc of diaphragms*, and is of great use in the illumination of objects, as will appear hereafter.

As the effect of the illuminators varies not only with their distance from the object, but also with the direction in which the light directed from them falls upon the object, provisions are made in mounting the microscope, by which various positions may be given to them, so that the light may fall upon the object in any desired manner.

In the frame in which the illuminator, M M, is mounted, it is customary to place two reflectors, one at each side, one concave and the other plane. By the former a converging, and by the latter a parallel pencil of light is reflected towards the object.

In this general illustration we have supposed the axis of the instrument to be vertical; it may, however, have any direction whatever; but whatever be its direction, the stage, S S, must always be at right angles and concentric with it. The eye-piece and object-piece are also supposed to be set in the same straight tube, with their axes set in the same straight line. This arrangement, though most commonly adopted, is neither necessarily nor always so. The tube which carries the eye-piece may, on the contrary, be inclined, at any desired angle, with that which carries the object-piece; for this purpose it is only necessary to place in the angle formed by the two tubes a reflector, so inclined that the rays coming from the object-piece shall be reflected along the axis of the tube which carries the eye-piece.

Fig. 46.—NACHET'S MULTIPLE MICROSCOPE.

THE MICROSCOPE.

CHAPTER III.

30. Oblique plane reflectors. THE SUPPORT AND MOVEMENT OF THE OBJECT: 31. The stage.—32. Mechanism for focussing.—33. Coarse adjustment.—34. Fine adjustment.—35. Method of determining the relief of an object.—36. Difficulty of bringing the object into the field.—37. Mechanism for that purpose.—38. Mechanism to make the object revolve.—39. Object to be successively viewed by increasing powers.—40. Slides to be cleaned.—41. Compressor.—42. Apparatus for applying voltaic current. THE ILLUMINATION OF OBJECTS: 43. Curious effects of light on objects.—44. Illumination by transmission and reflection.—45. Microscopic objects generally translucent, or may be made so.—46. Effects of varying thickness.—47. Varying effects of light and shade.—48. Uses of the Lieberkuhn.—49. Effects of diffraction and interference.—50. Use of daylight.—51. Artificial light.—52. Protection of the eye.—53. Pritchard's analysis of the effects of illumination.

30. Thus, for example, if the tube which carries the object-piece be vertical, a plane reflector, M M, fig. 15, receiving the rays

Fig. 15.

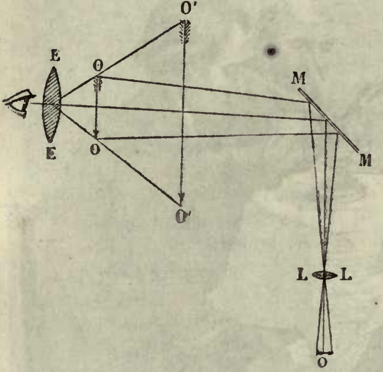
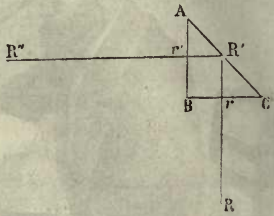


Fig. 16.



coming in a vertical direction from the object-piece, will reflect them horizontally to the eye-piece E E.

The same object would be attained with more advantage, and less loss of light, by means of a rectangular prism, A B C, fig. 16,

Fig. 17.

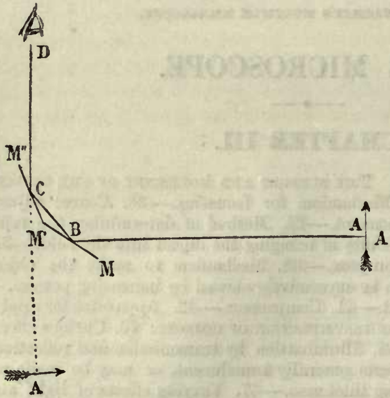
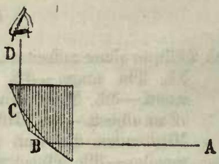


Fig 18.



the vertical ray, R R′ being reflected by the back, A C, of the prism in the horizontal direction R′ R″.

Since a single reflection thus made produces an inverted image,

it is sometimes preferable to accomplish the object by two successive reflections, as shown in fig. 17, where the ray, A B, is successively reflected at B and C to the eye at D. And the same object may be attained more advantageously by means of a quadrangular prism, as shown in fig. 18.

This application of the prism and reflector has been already explained in our Tract upon Optical Images.

Much practical convenience often arises from the adoption of this expedient; thus, while the object-tube is directed vertically downwards, to an object supported on a horizontal stage, or floating on or swimming in a liquid, the eye-tube may be horizontal, so that the observer may look in the level direction. In this case the two tubes are fixed at right angles, the reflecting surface being placed at an angle of 45° with their axes. We shall see hereafter a case in which, by the adoption of an oblique tube, several observers may at the same time, looking through different eye-pieces, see the same object through one and the same object-glass.

THE SUPPORT AND MOVEMENT OF THE OBJECT.

31. The appendage of the microscope, adapted for the support of the object is called THE STAGE.

Since every motion or disturbance by which the stage may be affected will necessarily be increased, when seen through the microscope, in the exact proportion of the magnifying power, it is of the utmost importance that it should be exempt from all tremor, and that it should have strength sufficient to bear, without flexure, the pressure of the hands in the manipulation of the object. When a high power is used, the focal adjustment of the instrument requires to be so exact, that a displacement of the object, which would be produced by the slightest pressure of the fingers upon a stage not very firmly supported, would throw it out of focus.

If the instrument be used for dissection, or any other purpose in which steady manipulation of the object is needed, it will be found convenient that the stage have sufficient magnitude to support both wrists, while the operation is performed with the fingers. Supports for the elbows ought also to be arranged, so as to place the operator completely at ease.

32. The instrument is focussed, as already explained, either by moving the stage to and from the body, or by moving the body to and from the stage. The motion is imparted to the one or the other by means of a milled head placed on the right of the observer, which leaves a pinion working in a rack to which the

part to be moved is attached. By turning this milled head one way and the other alternately, the observer finds by trial the position which gives greatest distinctness.

33. This, which is called the COARSE ADJUSTMENT, answers well enough when high powers are not used; but it must be remembered that as the teeth of the pinion successively pass those of the rack, the motion produced is not strictly an even and uniform one, but a sort of starting or intermitting motion, so that the instrument cannot be easily and steadily brought to rest at any intermediate point between the beginning and the end of the passage of a tooth. When high powers are used, and consequently an extremely nice adjustment of the focus required, this arrangement is therefore insufficient, and serves at best only for a first approximation to the exact focus.

34. A supplemental expedient is therefore provided in the best instruments, called the FINE ADJUSTMENT, which usually consists of a screw having an extremely fine thread, which being connected with the part to be moved, gives it a perfectly smooth, uniform, and slow motion, entirely free from starts or jerks.

In some of the best instruments these screws have as many as 150 threads to the inch, so that one complete turn of the milled head moves the stage or body through only the 150th part of an inch, and as the head is divided into ten equal parts and moves under an index, a tenth of a revolution can be observed, which corresponds to the 1500th part of an inch.

When the form of the object is not actually flat, and consequently all points upon it are not equally distant from the object-glass, they will not be all in focus together. When the distance of the object is such as to bring the more salient, and consequently the nearest, parts into focus, the more depressed parts will be too distant and consequently out of focus; and when the object is moved nearer to the object-glass by a space equal to the heights of the salient above the depressed parts, the latter will be in, and the former out of focus, and consequently the latter will be distinct, and the former confused.

When the powers used are so low that the distance of the object from the object-piece shall bear a considerable proportion to the difference of level of the salient and depressed parts of the object, this difference of level will not sensibly affect the focal adjustment; but when high powers are used, that difference of level bearing a very sensible proportion to the distance of the object from the object-glass, the adjustment which renders either distinct will render the other indistinct.

35. This optical fact has been converted with admirable address

into an expedient, by which the inequalities of the surface of a microscopic object are gauged, and its accidents analysed. Thus, for example, let the milled head of the fine adjustment be first turned so as to render the salient parts distinct, and let the position of the index be marked. Let it be then turned so as to render the depressed parts distinct, and let the new position of the index be marked. If one division of the head represent the 1500th part of an inch, the differences of level, of the salient and oppressed parts, will be just so many 1500ths of an inch as there are divisions of the milled head which have passed the index.

36. One of the first difficulties which the microscopic debutant encounters, is that which will attend his attempts to bring the object into the centre of the field of view when it is minute, and when the magnifying power is considerable. If he is only provided with a simple stage, without any mechanical expedient for moving the object, he will soon be oppressed with the fatigue arising from a succession of abortive attempts at accomplishing his purpose.

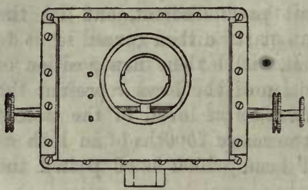
37. The entire diameter of the field of view will often be less than the 100th of an inch, so that a displacement of the slide so inconsiderable as to be utterly insensible to his fingers, will cause the object to jerk through a space greatly exceeding the entire extent of the field. In this way the object will start from side to side, the motion imparted to it by the touch to bring it back to the field being always in excess, however carefully and delicately the manipulation may be made. Some professional observers, by intense and long-continued practice, surmount this difficulty and succeed in adjusting the slides, even with the highest powers, without mechanical aid; but this is not to be hoped for by debutants or amateurs, except with very low magnifying powers. Such persons, if they would avoid the risk of throwing up the instrument with disgust, had therefore better in all cases be provided with a stage having some such expedients as we shall now describe.

Upon the fixed stage, such as it has been described, a second stage similar in form and equal in size is placed, and is moveable through a certain limited space right and left, by a fine screw with a milled head. Another similar stage is placed upon this, which partakes of any motion imparted to the latter, but which is also moveable upon the latter backwards and forwards by means of another fine screw. Upon this last stage the slide with the object is placed, and held down by springs so as to retain its place, whatever be the position of the stage.

By turning one of these screws (fig. 19), the object may be

slowly moved right and left, and by turning the other it may be moved backwards and forwards, and, in fine, by turning both at the same time it may be moved diagonally in any intermediate direction, according to the relative rate at which the one and the other milled head is turned. Sometimes the two milled heads are on the right side of the stage, so that they can be turned either separately or together by the right hand, and sometimes they are placed at opposite sides, so as to engage both hands.

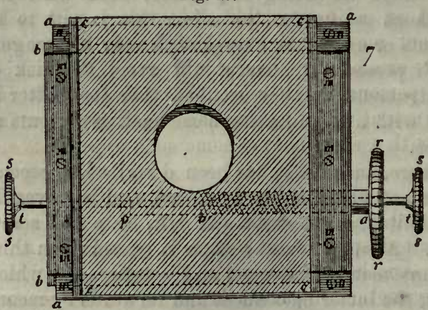
Fig. 19.



38. It is generally found convenient to have an easy means of turning the object round its centre, so as to present it to the light in all possible positions, without displacing it from the centre of the field. This is accomplished by inserting in the upper plate of the stage a metallic disc of somewhat greater diameter than the central aperture of the stage, which is so fixed as to be turned smoothly round its centre. It is upon this disc that the slide is placed and held by the springs which are attached to the disc so as to turn with it. This disc is sometimes graduated in 360°, so that the observer can turn the object through any desired angle, a power which will be found very convenient in certain classes of observations.

The arrangement consisting of a fixed with two moveable stages superposed is drawn in fig. 20, where *a a a a* is the fixed stage, and *b b b b*, *c c c c* the two stages which move in the grooves *n n* and *m m*, the one *b b b b* directed right and left, and the other *c c c c* backwards and forwards. The grooves in which the upper stage *c c c c* moves are formed in the lower stage *b b b b*, and those in which the latter moves are formed in the fixed stage *a a a a*. The one stage is moved by turning the milled heads *s s* fixed upon the

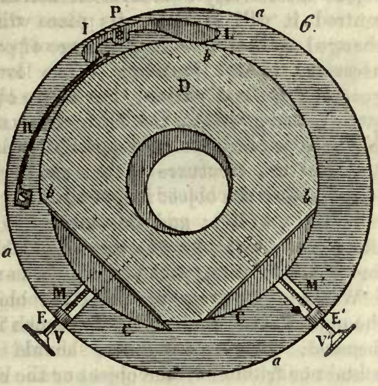
Fig. 20.



rod *t t*, and the other by turning the head *r r* fixed upon the hollow rod *v*, through which *t t* passes.

Another and more simple form of moveable stage is shown in fig. 21, where *a a a* represents a circular brass disc, having a circular aperture in its centre. Upon this a second disc *b b b* is placed, which is moved within certain limits in two directions, at right angles to each other, by the screws V V′, against which the spring R I P L reacts. The entire stage is in this case moveable round its own centre.

Fig. 21.



By these expedients the observer has complete command over the object, so as to be able to move it at pleasure in any direction, with a motion which will be smooth, slow, and free from jerks and starts, even when magnified with the highest powers.

To centre the object, that is, to place it on the stage so that its centre shall be in the centre of the field, is not so easy as it might appear to the unpractised in microscopic manipulation. To accomplish this, let the slide be first laid across the aperture of the stage, the object being as nearly as possible concentric with the aperture. Let the stage and object-glass be brought nearly, but not actually, into contact by the coarse adjustment. Let the slide be then again centred, so as to render the object concentric with the object-glass. Let the stage be then moved from the object-glass until the instrument is focussed as nearly as it can be by the coarse adjustment. Let the object be then more exactly centred by the stage-screws, and more exactly focussed by the fine adjustment.

It must not, however, be supposed that this elaborate process is necessary in the case of every class of objects. The larger sort can be easily enough centred by the hand, and focussed by the coarse adjustment; and in the cheaper description of microscopes no other means are provided. For a smaller sort, the centring may be effected by proximity with the object-glass, and rendered more exact with the fingers when no stage-screws are provided.

But much trouble will be produced when objects of the smallest class requiring the higher powers are examined with instruments in which the stage-screws and fine adjustments are not supplied.

39. In all cases it will be found advantageous to submit the object successively to a series of increasing powers. When once centred it will maintain its place while the object-lenses are changed, so that upon each change of power no new adjustment is necessary except focussing. The low powers will show the general form and contour, the entire object being at one and the same moment within the field. The next powers will show the larger parts, and the highest will display the texture of the surface and the structure of the smaller parts. By working the stage-screws the object is moved like a panorama across the field from right to left; and this motion is repeated for various positions given to it by the screws, which move it backward and forward until every part of it has been submitted to examination.

When high powers are used the object will be very close to the object-glass, so as almost to touch it when the instrument is focussed. In this case, care should be taken to prevent all contact or friction of the object or the slide with the object-glass, the latter being subject from that cause to injury or fracture. When it is desired therefore to change an object thus viewed with a high power, it is always advisable to separate the object-glass and stage by the coarse adjustment, before removing the one object and replacing it with the other, which must then be focussed.

40. The greatest care should be taken to clean the slides before placing them on the stage, since the least particle of grease or dust or any other foreign matter would, when magnified, injure the observation and might lead to errors.

When the object observed is in a drop of water or other liquid, or when it is itself a liquid, it will be included between the slide and a thin glass placed upon it, in which case it is of the greatest importance to exclude or remove all bubbles of air, since they would present appearances under the microscope, such as would deface those of the proper object of observation.

41. When it is required to submit a minute object to inspection, it is sometimes desirable to submit it to pressure, either to retain it in one position, if it be living, or to ascertain the effect of compression upon it, exercised in a greater or less degree for other purposes. It is often necessary also to roll it over, so as to present all sides of it in succession to the observer.

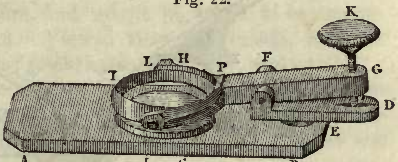
An instrument called a *compressor* has been contrived for this purpose, which has been constructed in a great variety of forms

by different makers, according to the demands of different observers.

One of the most common and useful forms of compressor is shown in fig. 22.

A small and very thin disc of glass is set in a brass ring I, and supported at two points L L, diametrically opposite, by the ends of a fork L P, attached to a lever P G, the latter being supported upon two upright pieces F, attached to an horizontal piece F D. This piece F D turns horizontally round a pivot, fixed near the end E of a strong slip of brass A B, having the form and magnitude of a slide used for the support of objects. At the middle C, of A B, is a circular hole, in which another disc of glass is set, corresponding in magnitude to the disc I. A screw, with a milled head K, works in the end G of the lever, by turning which in one way or the other, the end G, and consequently the disc I, is raised or depressed.

Fig. 22.



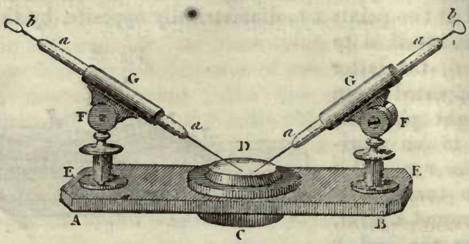
To place the object for observation, by moving the piece D round the pivot the ring I is removed from the lower disc C, upon which the object is then deposited. The screw K being turned, so as to raise the disc I sufficiently to prevent it from touching the object, the piece D is then turned on the pivot until the disc I is brought over the object. The observer then viewing the object in the microscope, and placing his hand upon the screw K, slowly turns it, so as gradually to compress the object, and continues this process or suspends it, or turns the disc I horizontally, so as to roll the object between the glasses, according as his course of observation may require.

The compression may be so increased as to flatten the object, which in some cases is desired, so as to render it more transparent, while nevertheless its form becomes more or less distorted.

42. It is sometimes required to ascertain the effects of an electric spark or voltaic current, transmitted through a liquid or solid, or through a body animate or inanimate. An apparatus adapted for this purpose is shown in fig. 23, where D C is a disc of glass set in the middle of a slip of brass A B. The two brass tubes G G play upon the hinges F F, which are supported on short glass pillars E E. Two glass tubes, through the bores of which fine platinum wires *a a* pass, are inserted tightly into the tubes G G, so that they can be pushed to, or drawn from the disc D,

where the object is placed. The positive and negative ends of the conductor of the electric machine, or the poles of a voltaic battery, being put in connection with the handles *b b* of the

Fig. 23.



platinum wire, the spark or current will pass from the point of one of the wires *a a* to that of the other, being transmitted through the object placed between them.

THE ILLUMINATION OF OBJECTS.

43. Among the accessories of the microscope, there is none the right use of which is more important than the illuminators. By the proper application of these, an infinite variety of beautiful effects are produced, and an infinite number of interesting consequences developed, while by their abuse, and by the misconception and misinterpretation of their indications, the most fatal errors and illusions may arise.

Let any one, however inexperienced in the manipulations of a microscope, applying one hand to the mirror and the other to the disc of diaphragms, vary at pleasure the position of the former, and turn the latter slowly round its centre, thus shifting the direction, and varying the quantity of the light which falls upon the object, and he will witness, in looking at the object through the instrument, a series of appearances which will soon demonstrate to him how curious, complicated, and important a part the illuminators play in microscopical phenomena.

44. Objects may be rendered visible in two ways, either by light reflected from those parts of their surfaces which are presented towards the observer, or by light falling on the posterior surface, and partially transmitted through them. Opaque bodies can be seen only in the former way, but translucent objects may be seen in either of these ways.

A translucent object presents a different appearance, according as it is seen by a front or back light. The leaf of a tree or plant, seen by reflected light, appears to have some particular tint of

green, showing faint traces of a certain reticulated skeleton of vegetable fibre. If it be held up before the sun, all light being excluded from the side presented to the eye, it will appear with a much paler tint of green, and the skeleton will become much more visible, the finer parts before invisible being distinctly seen.

A stained glass-window viewed from the outside appears to have dark and dull colours, and might be taken to be opaque, showing no form or design. Viewed from the inside, forms of great beauty, and colours of remarkable splendour, are seen.

When we say, therefore, that objects viewed in a microscope present very different appearances, according as they are illuminated by a front or a back light, we only state a general fact common to all visible objects.

No body can be said to be either opaque or transparent in an absolute sense. Bodies considered to be the most opaque, such as the metals, are found to be translucent when reduced to thin leaves. Even gold and platinum, the most dense of the metals, are rendered translucent under the hammer of the gold-beater, while glass, diamond, air, water, and similar bodies, commonly considered to be transparent, are proved to absorb a portion of the light transmitted through them, this absorption increasing with the thickness of the medium. There is in fine no body which will not become opaque if sufficiently thick, and none that will not become more or less translucent if sufficiently thin.

45. Since microscopic objects are generally of extremely minute dimensions, they are all, with some few exceptions, sufficiently translucent to be rendered visible by a back light.

It is well known that many bodies, which are opaque or nearly so, may be rendered translucent by saturating them with certain liquids. Thus, as every one knows, paper, linen, and other porous bodies, which when dry are imperfectly translucent, become much more so when wetted or oiled, or saturated with white wax.

This general physical fact has special and important application in the preparation of microscopic objects, which are saturated with various liquids, proper for each of them, by which they are rendered translucent.

When a translucent object is rendered visible by a back light, the intensity of the light must be regulated according to its translucency. The more translucent it is, the less intense must be the light. A strong back light thrown upon a very translucent object drowns it, and renders it altogether invisible. The light must therefore be reduced in intensity by varying the inclination of the reflector, the distance of the lamp from it, and by

the interposition of smaller diaphragms, until the best effect is produced. The observer will acquire by practice a facility in making these adjustments, so as to produce the desired result.

On the other hand, if the object be very imperfectly translucent, the light thrown upon it must be rendered as intense as possible by the contrary arrangements.

46. Different parts of the same object will generally have different degrees of translucency, and it will often happen that a light which would drown the more transparent parts will be no more than sufficient to display the more opaque parts. In such cases the observer will have to vary the light according as his attention is directed to one part or the other.

It must not be inferred that the darker parts are in this case really darker than those which are more transparent. The lesser degree of translucency more frequently arises from the different thickness of different parts of the object, the thicker parts absorbing more light, and therefore appearing of a darker tint than the thinner. If the varying transparency arise from this cause, the apparent lights and shadows or tints of colour must be taken as mere indications of the inequalities of thickness of a body of which the real colour is uniform.

The difficulty which an observer encounters in ascertaining the real form of an object, and the accidents of its surface when seen in a microscope by a back light, is partly owing to the fact that the eye is habituated to view objects almost exclusively by front lights, and the impressions produced of their forms are always deductions of which we are rendered unconscious by habit, by which the characters of these surfaces are inferred from the lights and shadows which are impressed on the organ of vision. Not having the same habit of seeing objects by a back light we cannot so easily make similar deductions, and we are apt to judge of the objects as if in fact they were illuminated with a front light.

The judgment is also more or less perplexed, and deceived by the fact that microscopic objects are as it were placed before the eye in an unnatural state of proximity, which give them a visual character totally different from that which objects have, viewed in the usual way with the naked eye.

It must be evident, therefore, how much attention and address on the part of the observer are indispensable to enable him to disentangle their physical causes from such complicated effects, and to give their appearances a right interpretation.

47. If an object, of which the surface is marked by numerous inequalities and asperities, be illuminated by a light which falls perpendicularly upon it, or which is scattered indifferently in all directions, an observer placed directly over it will be in general

unable to perceive the elevations or depressions, all being projected upon the same ground-plan, and all being similarly illuminated. But if the light fall upon it with a certain and regular obliquity, lights and shadows will be produced which will enable him to infer the accidents of the surface and the real form of the object.

The due consideration and application of this general optical fact will enable the microscopic observer to submit the object of his inquiry to such a visual analysis as will unfold at least a close approximation to its real form.

48. If the object be viewed by a front light proceeding from the concave mirror M M, fig. 13, or reflected by the Lieberkuhn, this effect will not be produced; for although the light reflected from the Lieberkuhn is not perpendicular to the object, it is scattered in all possible directions, so as utterly to remove all possibility of lights and shadows. An expedient is sometimes adopted in which light projected by a concave mirror or lens, properly placed, is directed only on one side of the Lieberkuhn, which is necessarily productive of lights and shadows.

But the purpose is much more simply and effectually attained by removing the Lieberkuhn altogether, and directing the illumination with the necessary obliquity upon the object by means of a reflector or lens placed as shown at M′ M′ or L L.

Those methods are always practicable except when a magnifying power is used so high as to render it necessary to bring the object almost into contact with the object-glass, in which case the mounting of the latter would intercept the light, whether proceeding from the Lieberkuhn, the lens, or mirror. In such cases the object can only be illuminated by a back light.

If the object be illuminated by a back light thrown obliquely upon it, the lights and shadows, strictly speaking, can only be produced upon the posterior surface. Nevertheless, the light passing obliquely through the anterior surface will produce dark and light tints, according to the angle at which it strikes the several superficial inequalities and accidents of that side of the object. It will be evident, therefore, that very complicated effects, in which the disentanglement of the forms which produce them is extremely difficult, must ensue.

Nevertheless, the attentive and practised observer, by presenting the illumination successively in various directions, by properly varying its intensity, and examining the object as well by front as by back illumination, when both are practicable, can generally arrive at a pretty clear knowledge of its form and parts.

49. When the object is illuminated by a back light, optical phenomena, called diffraction and interference, are produced,

against which the observer must be on his guard. The effects of these are to surround the outline of the object with coloured fringes. By limiting the illumination as far as it is practicable to the object itself, so as to avoid the transmission of any light through the opening of the slide, except what may pass through the object, this effect may be diminished or avoided.

Indeed, for many reasons, it is advantageous to prevent any light from passing through the slide, or through the opening of the stage, except what is employed in illuminating the object. All such light is liable to fall in greater or less quantity upon the object-glass, and, passing through it, has a tendency to render the image obscure and confused. For this reason, all extraneous light whatever should be as far as possible excluded from the space around the microscope, for all objects on which such light falls will reflect a part of it, some of which may fall upon the object-glass.

50. When the light of the sky or clouds is used, an aperture may be made in a window-shutter for its admission, all the other windows of the room being closed, and the light proceeding from the aperture being received upon the mirror or lens, by which it is directed and condensed upon the object. The light of a white cloud, strongly illuminated by the sun, is generally considered the best form of day-light which can be used, and that of a blue serene sky the worst. Observers differ as to the direct light of the sun, some maintaining that in no case whatever should it be used, while others give it a preference for minute objects seen under high powers, and therefore requiring intense illumination.

The light reflected from a white wall upon which the sun shines is a good source of illumination.

51. If artificial light be used with low powers, a common sperm candle will serve well enough, but means should be adopted to prevent the flickering of the flame.

An argand lamp, however, is, in all cases, preferable, as giving a steady invariable light. It will be improved if good olive oil be used instead of the fish oil.

The flame produced by the liquid known as camphine is especially pure and white, and well fitted for microscopic researches.

Whatever be the artificial light used, it ought to be surrounded with a shade, and so placed as to fall only upon the mirror or lens by which it is directed to and condensed upon the object.

52. It is advantageous to protect the eyes of the observer from extraneous light: the most simple and convenient method of effecting which is by a circular blackened pasteboard screen

about a foot in diameter, having a hole in its centre, through which the tube of the eye-piece is passed. This screen is then at right angles to the axis of the body of the instrument, the eye-piece projecting about an inch from it. The observer looking into the eye-glass with one eye, need not incur the exertion and fatigue of closing the other, since the screen performs the office of the eye-lid.

The mirrors are sometimes made with a concave glass at one side, and a plane glass at the other, the latter being used when condensation is not required. A disc formed of plaster of Paris, reduced to an extremely even and smooth surface, either plane or concave, is sometimes used with advantage when a soft and mild light is required. Nearly the same effect may be produced by placing a disc of white card upon the face of the mirror. The illumination by a back light is attended with a peculiar advantage, inasmuch as it displays the internal structure of objects, and, in the case of organised bodies, supplies beautiful means of exhibiting the circulation; as, for example, the circulation of the blood in animals, and the sap in vegetables. In the case of certain animalcules, it shows some living and moving within the bodies of others.

53. The following observations of Mr. Pritchard are worthy of attention:—"We must consider that in all bodies viewed by intercepted light, there is, properly speaking, neither light nor shade, in the ordinary acceptation of these terms; there are only dark and light parts, which again assume new aspects as the light is more or less direct or oblique. Thus depressions on transparent objects are almost sure, under the action of oblique light, to assume the effect of prominences; but prominences seldom or never have the semblance of depression. As almost all diaphanous bodies can be examined as opaque objects, a scrutiny of them in this way will generally be found greatly to assist our judgment concerning their nature, whether they admit of being cut into sections or not. It would be easy to write a volume on this subject only, if we commenced an illustration of particulars which could not be rendered clear and satisfactory without a vast number of figures. Long practice must, after all, determine our opinions, and scepticism should ever form a leading feature in them; we should *suspect rather than believe*.

"Opaque objects are not, upon the whole, so liable to produce optical deceptions as transparent ones, because we are more in the habit of viewing ordinary bodies by reflected or radiated light. The most common illusion presented by them is that of showing a *basso-relievo* as an *alto-relievo*; the reverse deception sometimes occurs also, but more rarely. This effect occurs in ordinary objects

viewed by the naked eyes, as well as in microscopes, especially if but one eye is employed. Thus, if we look intently for some time at a basso-relievo (a die of a coin, for example), *illuminated with very oblique light*, it at first appears in its true character; but, after a little while, some point on which we more particularly direct our gaze will begin to appear in *alt*, the whole rapidly follows; in a little time the effect wears off, and we again see it in bas-relief; then again in alt; and so on, by successive fits. This deception arises from the simple circumstance that *the lights and shades in bas-relief are very nearly like those of an alto-relievo of the same subject, illuminated from the opposite side;* our understanding in this case instantly corrects the false testimony of the eye, when we *consider from which side the light comes.* (If we observe with a microscope, we must remember that its image is inverted, and that in consequence the light must be considered as proceeding from the side of the field of view opposite to that where the source of illumination actually exists.) It will also be highly advisable, when we are in doubt as to the manner in which an instrument shows prominences and depressions, to verify its vision by observing some *known object* with it, of the real state of which, as to inequality of surface, we have been previously informed by the sense of touch, to which it has been well said there is no fellow." *

* "We usually see objects illuminated from *above* with the *shadows below* the prominences; now, unless the light is below an opaque object, when we view it in an engiscope, we shall see the *shadows above*, giving the prominences the appearance of depressions, and producing a very unnatural effect."

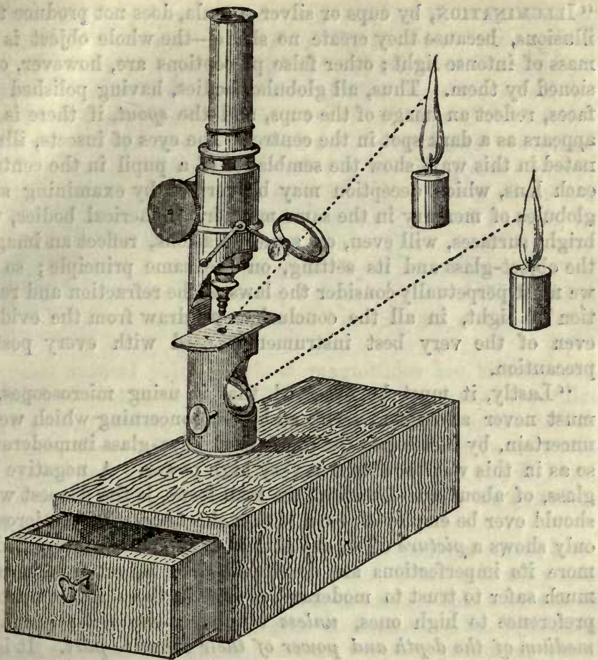


Fig. 36.—Frauenhoffer's Microscope.

THE MICROSCOPE.

CHAPTER IV.

Pritchard's analysis of the effects of illumination (continued). Measurement of objects: 54. Measurement distinct from magnifying power.—55. Measurement by comparison with a known object.—56. Micrometric scales.—57. Thin glass plates.—58. Micrometers.—59. Le Baillif's micrometer.—60. Jackson's micrometer.—61. Measurement by the camera lucida.—62. Goniometers. Magnifying Power: 63. This term much misunderstood.—64. Its exact meaning.—65. Least distance of distinct vision.—66. Visual estimate of angular magnitude.—67. Method of determining magnifying power by the camera lucida.—68. Dimensions of the least object which a given power can render visible.

"ILLUMINATION, by cups or silver specula, does not produce these illusions, because they create no shade—the whole object is one mass of intense light; other false perceptions are, however, occasioned by them. Thus, all globular bodies, having polished surfaces, reflect an image of the cups, and the *spout*, if there is one, appears as a dark spot in the centre. The eyes of insects, illuminated in this way, show the semblance of a pupil in the centre of each lens, which deception may be verified by examining small globules of mercury in the same manner. Spherical bodies, with bright surfaces, will even, on some occasions, reflect an image of the object-glass and its setting, on the same principle; so that we must perpetually consider the laws of the refraction and reflection of light, in all the conclusions we draw from the evidence even of the very best instruments, used with every possible precaution.

"Lastly, it must be observed, that in using microscopes, we must never attempt to verify an object concerning which we are uncertain, by increasing the depth of the eye-glass immoderately, so as in this way to obtain a very high power. A negative eye-glass, of about one-fourth of an inch focus, is the deepest which should ever be employed, even with a short body; for a microscope only shows a *picture* of an object, and the more it is amplified the more its imperfections are developed. It is, on this account, much safer to trust to moderate powers in these instruments, in preference to high ones, *unless they are obtained through the medium of the depth and power of their objective part.* It is the nature of deep eye-pieces to cause all luminous points to swell out into discs, and to render the image soft, diluted, and nebulous, at length all certain vision fades away, and the imagination is left to its uncontrolled operation. Single and compound magnifiers, having to deal with the real object, may be made of any power which can be used; and if our eyes are strong, and habituated to their use, we may place great reliance on their testimony; but we must never allow them to persuade us to believe marvels which are manifestly impossible, or contrary to the known laws of nature and right reason."

MEASUREMENT OF OBJECTS.

54. The determination of the real magnitude of microscopic objects, and that of the magnifying power of the instrument, are problems closely connected but not identical. Either may be solved independently of the other.

55. If two objects be placed at the same time within the field of view, the real magnitude of one of which is known, that of the other may be at least approximately estimated by comparison.

Since they are equally magnified, their real will be in the proportion of their apparent magnitudes. If, therefore, they appear equal, they will be equal, and if that which we desire to measure appear to be twice or half the size of that whose magnitude we know, its real magnitude will be twice or half that of the latter.

Such was the micrometric method used by the earlier observers. Thus Lewenhoeck procured a number of minute grains of sand, sensibly equal in magnitude, and placing as many of them in a line, and in contact, as extended over the length of an inch, he ascertained the fraction of an inch, which expressed the diameter of each. When he desired to ascertain the actual magnitude of an object seen with his microscope, he placed one of these grains beside it, and estimated by comparison the magnitude of the former.

Various natural objects, whose magnitudes are known, and which are subject to no perceptible variations, such as the sporules of Lycoperdon bovista or puff-ball, whose diameter is the 8500th of an inch, those of the lycopodium, which measures the 940th of an inch, and others such as hair, the filaments of silk, flax, and cotton, and the globules of blood, have been suggested as standard measures to be similarly used.

More modern observers, adhering to the same method, have substituted artificial for natural standards. Thus extremely fine wire, called micrometric wire, has been used. This wire can be drawn with an astonishing degree of fineness. Dr. Wollaston invented a process by which platinum wire was produced, whose thickness was only the 30000th part of an inch.*

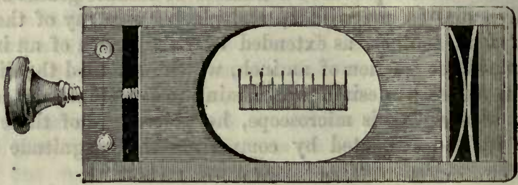
56. Such measurements are now more generally made by means of a minute scale engraved on glass, with a diamond point. Let us suppose, for example, a line, the 20th of an inch in length, traced across the centre of a glass disc, set in a thin brass plate of the size and form of the sliders on which objects are mounted. Let this line be divided into 100 equal parts, every fifth division being distinguished by a longer line, and every tenth by a still longer one. Each of these divisions will be the 2000th part, the intervals between the fifth divisions will be 400th, and that between the tenth divisions the 200th part of an inch. This microscopic scale will be seen magnified with the microscope, and any microscopic object laid upon it will be seen equally magnified, so that its dimensions can be ascertained by merely counting the divisions of the scale included between those which mark its limits when placed in different positions on the scale.

It may perhaps be thought impracticable to make divisions so

* Handbook of Natural Philosophy, 2d edition, Mechanics, 38.

minute upon the glass, with the necessary precision, especially when it is remembered that any error or inequality will necessarily be augmented in the exact proportion of the magnifying power with which such a scale is seen. Nevertheless this difficulty has been most successfully overcome, and combinations of screws and

Fig. 24.



wheels have been contrived, by which the diamond point is moved by self-acting mechanism, so as to trace the successive divisions of scales of astonishing minuteness. Scales are thus produced, the divisions of which are no greater than the 25000th part of an inch.

This extreme minuteness is, however, rarely necessary or desirable in microscopic researches, and the divisions of the scales in more common use vary from the 1000th to the 2000th of an inch. In the scales delivered with moderately good French instruments, a millimetre is divided into one hundred parts. A millimetre being about the 25th of an inch, these divisions would therefore be the 2500th of an inch. (See Tract on Microscopic Drawing and Engraving, Museum, vol. vi.)

The process described above, in which the object is measured by superposition upon the micrometric scale, is attended with several practical difficulties and objections. The object, when thus placed, is always nearer to the object-glass than the scale, and when it is in focus, the scale is out of focus and invisible; and, on the other hand, when the scale is in focus, the object is out of focus and indistinct. When low powers only are used, this difference between the focus of the object and that of the scale being inconsiderable, will not prevent the success of the operation; but when the powers are high, it can never be satisfactorily, and sometimes not at all effected.

There is still another objection to the process. The placing and displacing of objects frequently on a surface so delicately engraved, subjects it to friction, which soon spoils and effaces the divisions.

If the divided surface be protected, as it may be, by a plate of glass laid upon it, the difference between the distances of the object and the scale from the object-glass is augmented by the

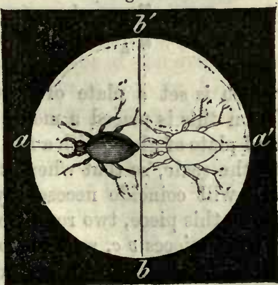
thickness of the glass which covers the scale; and however thin this glass may be, where high powers are used, it will render the difference of the foci of the scale and the object so sensible, that they can never be both seen with sufficient distinctness at the same time.

57. We know no greater example of the inexhaustible resources of art, and the untiring zeal with which its cultivators minister to the wants of science, than the wonderful perfection to which the mechanical division of a material so fragile as glass has been carried. For the reasons we have here stated, as well as because in the application of the highest magnifying powers the object-glass of a microscope requires to be almost in contact with the object, without actually touching it, microscopists required extremely thin plates of glass to cover delicate objects mounted on their slides. Messrs. Chance of Birmingham responded to this demand by the production of plates of glass so thin, that three hundred of them piled one upon the other are no higher than an inch.

For examples still more striking of the minuteness with which lines may be traced upon glass by mere mechanical processes, we may refer the reader to that part of our Tract upon Microscopic Drawing and Engraving, in which the test plates of Mr. Nobert are described.

58. One of the most evident expedients for the measurement of microscopic objects would seem to be the micrometer screw, which is applied with so much success, and with results of such extreme precision, in astronomical instruments. Various methods of applying it to the microscope will suggest themselves to every one who is familiar with its uses in the observatory. Let two filaments of spider's web, or micrometric wire, be extended at right angles across the field in the focus of the eye-piece. These will divide the field horizontally and vertically at right angles, intersecting at its centre, as shown in fig. 25. Now suppose the stage supporting the object is capable of being moved by a micrometer screw, having for example one hundred threads to the inch. Let the object be placed first so that its length shall be horizontal, and let the slip be adjusted so that the vertical micrometric wire *b b′* shall coincide with one of its extremities. Let the micrometer screw be now turned so that the object shall move horizon-

Fig. 25.



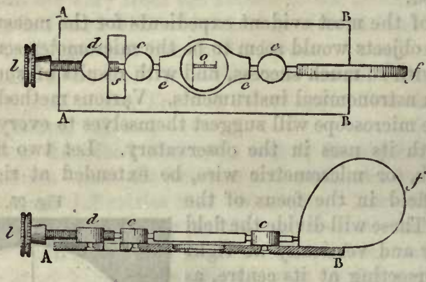
tally. It will appear to pass gradually under the vertical wire until its other extremity shall coincide with that wire. If then the number of complete turns, and parts of a turn of the screw be counted, the length of the object then will be known. Thus, if at the end of every complete turn, the screw produce an audible sound like the tick of a clock, the observer can count the complete turns, and if the circumference of the head be divided into 100 parts, and that an index be fixed upon the stage to indicate the position of the head at the commencement, the decimal parts of a turn can be ascertained, each division of the head corresponding to the 100th part of a complete turn, and therefore to the 10000th of an inch.

By turning the stage so that the screw will cause the object to move across the field in the direction of the vertical wire, its dimensions in the other direction can be ascertained.

59. A simple and ingenious micrometer for ascertaining the dimensions of such objects as would bear a slight pressure without change of form, was invented by M. Le Baillif. A plan and vertical section or side view of this are shown in fig. 26.

Two upright pieces, *c c*, are fixed in a slip of copper, formed like one of the slides, having a circular hole in its centre, in

Fig. 26.



which is set a plate of glass, on which a scale *o* is engraved. Upon this is placed a moveable piece, *e e*, having a similar hole and plate of glass, with a fine line engraved upon it at right angles to the scale, so that when it is moved from left to right this fine line will coincide necessarily with all the divisions of the scale. From this piece, two rods proceed, which pass through holes in the upright pieces *c c*, and one of them is reacted upon by a piece of watch-spring, *f*, while the other abuts against the end of a fine screw, *l*, which moves in a nut, *d*.

When an object is to be measured, the index line upon the upper glass disc is brought to coincide with the first division or

zero of the scale by turning the head *l* so as to cause the screw to retire from the piece *e e*, the spring *f* then pressing this piece towards the screw. The object to be measured is then inserted between the end of the rod projecting from *e* and the screw, and consequently the piece *e e* and the index line engraved upon it will be pushed from left to right through a space equal to the thickness of the object. This thickness may then be ascertained by observing with the microscope the division of the scale to which the indicating line has been advanced.

60. A micrometer, having some resemblance to this, but made more applicable to the general purposes of microscopic measurement, has lately been contrived by Mr. Jackson, a description of which is published in the "Transactions of the Microscopical Society."

A disc of glass, upon which a micrometric scale is engraved, is set in a thin plate of brass, which moves with a sliding motion on another plate, in which a corresponding hole is made. The former is like that of M. Le Baillif, urged by a fine screw in one direction, and driven back by a spring in the other, as shown in fig. 24.

Fig. 27.

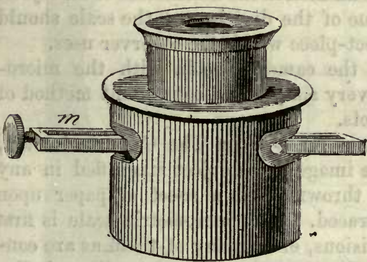
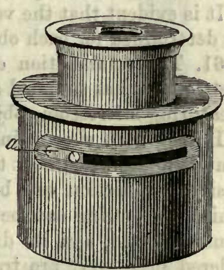


Fig. 28.



This micrometer slide is inserted in the tube of the eye-piece by openings in the sides of the tube, as shown at *m* in fig. 27, which openings can be closed when the micrometer is not used by sliding covers, as shown at *a*, fig. 28.

It is easy to see how this contrivance is applied. The scales magnified by the eye-glass are projected upon the optical image of the object produced by the object-glass, and this image may be made to move so as to bring its extremity to coincide with the first division of the scales. The scale will then show not only the dimensions of the entire object, but those of its parts. The object may be turned in any direction relatively to the scale that may be desired, by means either of the hand or the stage adjustments.

It is necessary, however, before applying this micrometer to the measurement of objects, to ascertain the value of the divisions of the scale relatively to the object, since the immediate subject of its measurement is, not the object itself, but the optical image of the object produced in the focus of the eye-piece by the object-glass; and this preliminary valuation is the more necessary, inasmuch as the relative magnitude of the image, compared with that of the object, will vary with the power of the object-piece.

To ascertain, then, the value of the divisions of the scale, let another micrometric scale, the divisions of which are known, be placed upon the stage. An image of this scale, magnified as that of an object would be, will then be formed in the focus of the eye-piece, and the other scale will be seen projected upon it. Let the position of the two scales be so adjusted by the stage arrangements that the first division of the one shall be projected on the first division of the other. By observing then the next divisions of the two which coincide, the relative value of the scales will be known. Thus if ten divisions of the eye-piece scale exactly cover 100 divisions of the other, and if each division of the latter be the 1000th of an inch, one division of the eye-piece scale will correspond to the 10000th part of an inch in the dimensions of an object.

It is evident that the value of the divisions of the scale should be determined for each object-piece which the observer uses.

61. The combination of the camera lucida with the micrometric scale has supplied a very simple and convenient method of measuring microscopic objects.

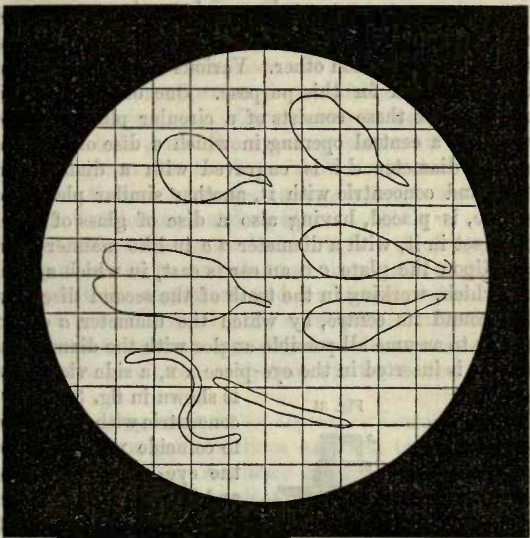
It has been shown in our Tract upon The Camera Lucida, that by that instrument the image of an object magnified in any desired proportion can be thrown upon a sheet of paper upon which its outline can be traced. The micrometric scale is first thus projected, and its divisions, or as many of them as are considered necessary, are traced upon the paper. Another similar series of divisions being traced at right angles to the former, the part of the paper corresponding to the field of view is divided into a system of squares, like those into which a map is divided by the lines of latitude and longitude. The micrometric slide being removed from the stage, the slide with the object is substituted for it, and the observer sees the image of the object similarly magnified projected upon the paper, already spaced out by the squares. He can therefore count the number of squares occupied by its length and breadth, and by the length and breadth of its several parts, or, better still, he can trace its outline upon the paper, so that its dimensions and those of all its parts can be exactly ascertained. Thus, if each division of the scale is the 1000th of an inch, the side of each square will represent the

1000th of an inch, and these sides may themselves be easily subdivided into ten or 100 parts, so as to carry the measurement to 10000ths or 100000ths of an inch.

In fig. 29 the field of view is represented spaced out in this manner, with the outlines of objects traced upon it.

Such a scale once drawn upon the paper, will serve for the measurement of any objects which may be submitted to the microscope; but it is most essential that in all such measurements the paper be kept at exactly the same distance from the camera, and that neither the object-glass, the eye-glass, nor the stage shall suffer any change in their relative positions.

Fig. 29.



It has been shown that the magnitude of the image received on the paper increases with the distance of the paper from the camera. If, therefore, the paper be placed at a greater or less distance from the camera to receive the image of the object than that at which it was placed to receive the image of the micrometric scale, the image of the object will be produced upon a scale greater or less than that on which the image of the micrometric scale was produced, and consequently the one cannot be taken as a measure of the other.

If any change be made in the relative positions of the eye-

piece, object-piece, and stage, a corresponding change would be made in the magnifying power of the instrument, and a consequent change in the dimensions of the picture of any object projected by the camera on the paper, though no change be made in the distance of the paper from the camera.

In fine, the method of measuring the actual dimensions of a microscopic object by means of a scale drawn with the aid of the camera, requires that the instrument and the paper shall be in precisely the same state when the image of the object is projected on the paper as they were when the scale was drawn upon the paper.

If this condition be observed, measurements can be made by the camera with all the necessary facility and precision.

62. In microscopic researches it is frequently necessary to measure the angles at which the lines which form the contour of objects are inclined to each other. Various forms of *goniometers* * have been contrived for this purpose. One of the most simple and convenient of these consists of a circular plate of brass C C, fig. 30, having a central opening in which a disc of glass is set, on which a diameter *d b* is engraved with a diamond point. Upon this, and concentric with it, another similar plate, toothed at the edge, is placed, having also a disc of glass of the same magnitude set in it, with a diameter *a c* in like manner engraved upon it. Upon the plate C C an ear is cast, in which a pinion is inserted, which, working in the teeth of the second disc, gives it a motion round its centre, by which the diameter *a c* is made successively to assume all possible angles with the diameter *d b*.

This piece is inserted in the eye-piece A B, a side view of which is shown in fig. 31, so as to be concentric with the lenses, and to coincide with the focus of the eye-lens. The lines *a c* and *b d* will then be seen projected on the image of the object, and if the vertex of the angle it is desired to measure be brought, by means of the stage adjustments, to coincide with the centre O of the disc *a b c d*, where the two engraved diameters intersect, and so that one side of the angle to be measured shall coincide with the fixed line *d b*, the line *a c* can be turned by the pinion F, until it shall coincide with the other side. A graduated circle which surrounds the disc will then show the magnitude of the angle at which *b d* and *a c* are inclined.

Fig. 30.

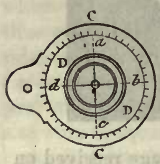
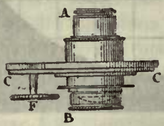


Fig. 31.



* From the Greek word γόνυ (*gonu*), knee.

THE MAGNIFYING POWER.

63. It has been well said, that a question clearly put is half resolved. There is no term in microscopic nomenclature so familiar to the ear, and so flippant on the tongue, as the "magnifying power;" yet there is none respecting which there prevail so much confusion and obscurity. The chief cause of this is the neglect of a clear and distinct definition of the term.

It has been already shown, that the magnitudes observed with the microscope are visual, not real. We can say that such or such an object seen in the microscope has a magnitude of so many degrees, but not at all one of so many inches. Strictly speaking, the same is true of all objects seen in the ordinary way; but in that case the mind is habituated to form an estimate of their real magnitudes, by combining the consideration of their apparent magnitudes with their distances. It is true that we are unconscious of the mental operation from which such estimates result, but it is not the less real. Our unconsciousness of it arises from the force of habit, and the great quickness of the acts of the mind. Every one who has been familiar with intellectual phenomena knows that such unconsciousness is found to attend all such acts as are thus habitual and rapid.

64. But when objects are looked at in a microscope, the mind not only does not possess the necessary data to form such an estimate, but the conditions under which the visual perceptions are formed are so unusual, and, so to speak, unnatural, that it is incapacitated to form an approximate estimate even of the visual, to say nothing of the real, magnitude of the object of its perception.

The visual magnitude of an object, as seen in a microscope, is the angle of divergence of lines supposed to be drawn from the eye to the limits of the imaginary image formed by the eye-glass, which is the immediate object of perception. When we say, therefore, that the instrument has such or such a magnifying power, every one will comprehend that it is meant that this visual magnitude is so many times greater than the visual magnitude which the object would have, if it were seen in the usual way without the interposition of any optical expedient.

So far all is clear, and so far there can be no difference of opinion on the point, provided only that the latter member of the sentence be clearly defined. What is the "visual magnitude *seen in the usual way?*" There are many ways of looking at an object, and "the usual way" depends much on the magnitude of the object. We can see well enough the dome of St. Paul's Cathedral at the distance of half a mile, while we cannot see a

small insect at the distance of a yard. The same object may be viewed at different distances, and will have different visual magnitudes, these magnitudes being greater as the distance is less. The visual diameter of a small object, seen from the distance of a yard, is three times less than when seen from the distance of a foot. It appears, therefore, that the "visual magnitude of an object seen in the usual way with the naked eye," is a term of comparison which, without some further condition to limit it, has no fixed meaning, and consequently leaves the "magnifying power" of which it is made the standard, altogether vague and indefinite.

65. The visual magnitude therefore which is made the standard of magnifying power, must be the visual magnitude at some arbitrary distance conventionally assumed. As we have already stated, it has been generally agreed, since micrography has taken the rank of a special branch of science, to adopt ten inches as the standard distance. This distance is recommended not merely on account of the arithmetical facility which arises out of its decimal character, but because it agrees sufficiently for all practical purposes with the standard derived from the measures of other countries. In France, for example, the standard usually adopted is twenty-five centimètres, which is equal to 9·427 inches, being less than ten inches by only about the sixth of an inch.

According to this convention, then, the magnifying power of a microscope would be the number of times the visual diameter of the object viewed with the microscope is greater than its visual diameter viewed by an eye placed at ten inches from it. Thus, if the visual diameter of an object seen at the distance of ten inches be fifteen minutes of a degree, and the visual magnitude of the same object seen with a microscope be two and a half degrees, or 150 minutes, the magnifying power will be ten.

But an objection will even still be raised. The object may be so small that at the distance of ten inches it would not be visible at all with the naked eye. Nay, it may be, and in the case of microscopic objects often is, so minute that it would not be perceptible to the naked eye at any distance, however small. In that case it may be asked, What is to be understood by "its visual magnitude at the distance of 10 inches?"

This point will require some explanation. There is a certain limit of magnitude within which an object will cease to make any sensible impression of its magnitude or form upon the eye. This minor limit of magnitude varies with different individuals, and, in the case of the same individual, with different objects according to their colour, illumination, the ground on which they are projected, and many other conditions which it is not here necessary to

discuss. It will suffice to say that there is such a limit. If the visual angle formed by lines diverging from the eye to the extremities of the object be within this limit, the object will not be perceived; or, to speak with more rigour, its magnitude and form will not be perceived.*

In such cases, therefore, the visual magnitude of an object, without the intervention of the microscope, must be understood to mean the angular divergence of the rays which would be drawn from a point placed at ten inches from the object to its extremities. This would be the visual magnitude of the object "*if it could be seen*" at that distance.

In fine, therefore, the definition of the magnifying power of a microscope will be clear, distinct, and adequate, if it be stated thus:—It is the quotient which would be obtained by dividing the visual magnitude of the object, as seen in the microscope, by the visual magnitude which the object would have to a naked eye placed at ten inches distance from it, supposing the eye to have sufficient sensibility to perceive it at that distance.

Every one is more or less familiar with real magnitude, so that when an object of ordinary dimensions is placed before them they can give at least a rough estimate of its actual dimensions. The same facility of estimating visual magnitude does not exist, although, in fact, we receive the impressions of visual much more frequently than those of real magnitude. The estimate of visual magnitude, however, enters into all microscopic inquiries as an element and condition of such importance, that all those who use the instrument, whether for the purposes of serious research or rational amusement and instruction, would do well to familiarise themselves with it. Some observations illustrative of such sensible impressions will therefore, we presume, be not unacceptable to our readers.

66. Our great familiarity with real magnitude arises from our intimate knowledge of certain standard units by which it is counted. There is no one, however little educated, that has not a pretty clear notion of the length expressed by an inch, a foot, and a yard. Let us see whether we may not enable any one with common attention to acquire an equally clear notion of the standard units of visual magnitude.

Every one is familiar with the apparent magnitude of the disc of the full moon. It is visible to the whole world, and seen for several nights in each month during the entire life of every individual. Now it happens that the visual magnitude of its diameter

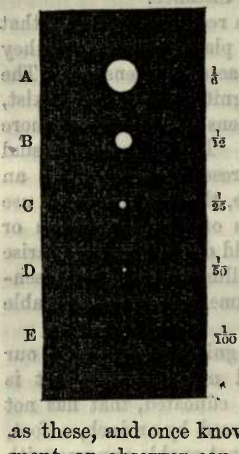
* The fixed stars are visible as mere luminous points, but their forms and magnitudes are not perceivable, owing to the extreme smallness of their visual angle produced by their enormous distances.

is just *half a degree*, which means, that the angular divergence of lines drawn from the eye to the extremities of the diameter is the same as that of two lines drawn from the centre of a circle to the extremities of an arc, which is the 720th part of the entire circle. Every one, therefore, who is familiar with the appearance of the full moon, will be as familiar with the meaning of a visual angle of half a degree, and, consequently, of a degree as they are with the real magnitude of an inch or a foot.

The distance of the moon has been ascertained to be 120 times its own diameter, and it is evident that any circular disc whatever, whose distance from the eye is 120 times its own diameter, will have a visual angle equal to the diameter of the moon, and therefore to half a degree; and, consequently, one whose distance is sixty * times its own diameter, would have a visual angle of a degree.

Thus, in fig. 32, there are five white discs shown upon a black ground: the diameter of the first is the 6th of an inch; that of the second, the 12th; that of the third, the 25th; the fourth, the 50th; and the fifth, the 100th. If these be held at ten inches from the eye, the first disc, A, will have a visual angle of 1°; the second, B, one of 30′; the third, C, about 15′; the fourth, D, $7\frac{1}{2}$′; and, in fine, the fifth, E, $3\frac{3}{4}$′.

Fig. 32.



It follows, therefore, that an object which when viewed with a magnifying power of 1000, appears with the same visual diameter as the moon, or as the disc B, fig. 32, placed at 10 inches from the eye, must have a real diameter no greater than the 12000th part of an inch.

Having familiarised himself with some such standards of visual magnitude as these, and once knowing the magnifying power of his instrument, an observer can easily make a rough estimate of the real magnitudes of the objects under view.

67. But for this, as well as many other purposes of microscopic research, it is necessary that the actual magnifying power of the instrument be ascertained.

The most simple and direct means of accomplishing this are supplied by the camera lucida.

* More strictly 57·3 times; but the round number will be sufficient for the above illustration.

Let a micrometric scale, such as we have already described, be placed on the stage, the instrument focussed, the camera attached, and a sheet of paper placed at 10 inches from it. An image of the scale being seen on the paper, let any two contiguous divisions of it be marked with the pencil. Let the distance between these marks be then exactly measured, and let it be divided by the actual length of the divisions of the scale. The quotient will be the magnifying power.

Thus, for example, let us suppose that the micrometric scale is the 25th part of an inch, and that this length is divided into 100 parts, each of these parts will be the 2500th part of an inch. Now suppose that it is found that the distance between the images of two contiguous divisions on the paper, is four-tenths of an inch. It will follow that the visual magnitude of a division of the scale is magnified in the proportion of $\frac{1}{2500}$ to $\frac{4}{10}$, that is, as 1 to 1000. The magnifying power would therefore be a thousand.

There are other methods of ascertaining the magnifying power, but this is so simple, so easily produced, and so precise, that we shall not detain the reader by any notice of others.

Microscopes being generally supplied with several object-glasses, and eye-pieces, the observer and amateur would do well once for all to ascertain the magnifying powers of all the possible combinations of them, and to tabulate it and keep it for reference.

68. It is often asked, What are the dimensions of the most minute object which a microscope, having a given magnifying power, is capable of rendering distinctly visible?

The answer to this question will depend on the answer to another; What are the least dimensions of the same object, with which it would be distinctly visible, at ten inches distance, with the naked eye?

Whatever be the latter dimensions, the former will be just so many times less as there are units in the number which expresses the magnifying power.

Thus, for example, if the smallest linear dimensions with which the object could be distinctly seen without a glass at 10 inches distance were the 300th part of an inch, a microscope having a magnifying power of 500 would render such an object equally visible if its linear dimensions were only the $300 \times 500 = 150000$th part of an inch.

It is generally considered that the smallest disc of which the form can be distinguished by the naked eye, being properly contrasted with the ground upon which it is seen, is one which would have a visual angle of one minute; and since a line measuring the 360th part of an inch, placed at ten inches distance, would

have that visual angle, it would follow that the smallest object of which the form could be rendered distinctly visible by a microscope of a given magnifying power, would be one whose linear dimensions are as many times less than the 360th part of an inch as there are units in the number expressing the magnifying power.

It must not be forgotten, however, in considering such points, that the smallest object whose form can be distinctly seen at a given distance without a glass, depends on many conditions, some connected with the object, and some with the observer, as has been already stated.

Many persons fall into the error of supposing that the excellence of a microscope is to be determined by the greatness of its magnifying power. On the contrary, that instrument must be considered the most efficient which renders the details of an object perceptible with the lowest power. Distinctness of definition, by which is meant, the power of rendering all the minute lineaments clearly seen, is a quality of greater importance than mere magnifying power. Indeed, without this quality, mere magnifying power ceases to have any value, since the object would appear merely as a huge misty silhouette.

Sufficiency of illumination is another condition which it is difficult to combine with great magnifying power, but which is absolutely necessary for distinct vision.

If two instruments show the same object with equal distinctness of definition and with sufficiency of illumination, one having a higher magnifying power than the other, then it must be admitted that the one which bears, with such conditions, the higher power is the more efficient instrument.

The mere magnifying power depends on the focal length of the lenses, the illumination on the angle of aperture, and the distinctness of definition on the extent to which those conditions have been fulfilled which confer upon the combination of lenses composing the instrument, the qualities of aplanatism and achromatism.

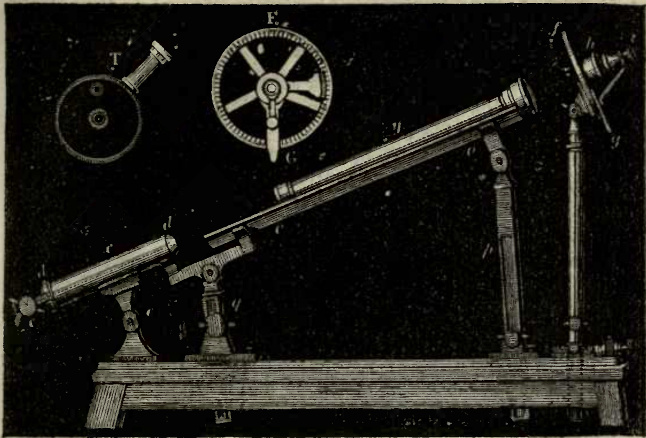


Fig. 35.—Biot's Polariscope.

THE MICROSCOPE.

CHAPTER V.

Micropolariscope: 69. Polarisation.—70. Condition of a polarised ray.—71. Polarisation by double refracting crystals.—72. Their effect upon rays of light.—73. The micropolariscope. The mounting of microscopes: 74. Conditions of efficient mounting.—75. Frauenhoffer's mounting.—76. Methods of varying the direction of the body. Chevalier's universal microscope: 77. Mounting of this instrument.—78. Method of rendering it vertical.—79. Method of adapting it to the view of chemical phenomena.—80. Method of condensing the light upon the object. Ross's improved microscope: 81. Useful labours of Mr. Ross.—82. Details of his improved microscope.

THE MICRO-POLARISCOPE.

69. When a ray of light has been reflected from the surface of a body under certain special conditions, or transmitted through certain transparent crystals, it undergoes a remarkable change in its properties, so that it will no longer be subject to the same effects of reflection and refraction as before. The effect thus produced upon it, has been called polarisation, and the ray or rays of light thus affected are said to be polarised.

The name POLES is given in physics in general to the sides or ends of any body which enjoy or have acquired any contrary properties. Thus, the opposite ends or sides of a magnet, have contrary properties, inasmuch as each attracts what the other repels. The opposite ends of an electric or galvanic arrangement are, for like reasons, denominated poles.

70. Following the common rule of analogy in nomenclature, a ray of light which has been submitted to reflection or transmission under the special conditions referred to, has been called polarised light; inasmuch as it is found that the sides of the ray which lie at right angles to each other, possess contrary physical properties, while those of a ray of common or unpolarised light possess the same physical properties.

To illustrate the relative physical condition of common light and polarised light, we may compare a ray of common light to a round rod or wire of uniform polish and uniformly white, while a ray of polarised light may be compared to a similar wire, two of whose opposite sides are rough and black, while the other opposite sides at right angles to these are polished and white. Thus, if A B C D, fig. 33, be a section of the former, the entire circumference A B C D is white and polished, and if A′ B′ C′ D′

Fig. 33.

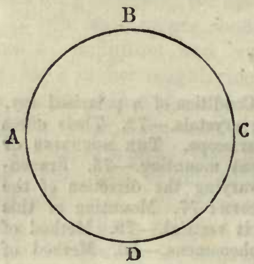
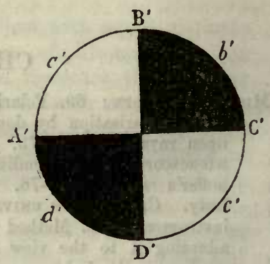


Fig. 34.



be a section of the latter, A′ B′ and C′ D′ will be white and polished, while B′ C′ and D′ A′ will be black and rough.

A group of physical properties, very numerous and complicated, characterise the polarised state of light, the discussion and exposition of which, constitute the subject of an extensive and important section of optics. It would be obviously impossible here to convey to the reader any general idea of these; nevertheless, as an illustration of them, one of the most frequent occurrence may be mentioned. If a ray of common light fall upon a smooth and polished surface, it is always reflected according to the well-known laws of reflection, no matter what side of it may be pre-

sented to the reflecting surface. If a polarised ray, however, fall at a certain inclination upon the same surface, it will be reflected or absorbed according to the side of it which is turned towards the reflecting surface. Thus, if the side A′ B′ or C′ D′ be presented towards the reflecting surface, the ray will be reflected as if it were common light, but if the side B′ C′ or A′ D′ be turned towards the reflecting surface, it will not be reflected at all, but will be, as it were, smothered or extinguished.

The sides A′ B′ and C′ D′, which are opposite to each other, have, therefore, a property contrary to that of the sides B′ C′ and A′ D′, so that they are respectively called the poles of the ray, just as the ends of a voltaic circuit having contrary electric properties are called the positive and negative poles of the voltaic battery, and the ends of a magnet are called its boreal and austral, or south and north poles.

The effects which polarised light produces when it falls upon, or is transmitted through, various substances, more especially such as are in the state of crystallisation, are of the highest physical importance, being in most cases the indication of molecular and other properties, by which optics has been placed in relation with, and has become the handmaid of, almost every other branch of physical science.

71. There are various expedients by which a ray of common light can be polarised. It will be polarised if it be reflected at a certain inclination, called from that circumstance the angle of polarisation, from certain surfaces. Each substance has its own angle of polarisation. That of glass, for example, is $35\frac{1}{4}°$. It is also polarised if it pass through certain transparent crystals. Some of these, while they polarise the ray, split it into two, both being polarised, but in planes at right angles to each other; that is, for example, the sides A′ B′ and C′ D′ being white in one, and black in the other.

The well-known mineral called Iceland spar is an example of this class of crystals.

Such crystals are called double-refracting crystals, because the two rays into which the ray of common light is split are refracted by the crystal in different directions, and according to different laws.

When a polarised ray is transmitted through such a crystal, according to certain conditions, it will either pass through it, as it would through any ordinary transparent medium, or will be extinguished by it, according to the side of the ray to which certain faces of the crystal are presented. Such crystal is related to the poles of the ray, therefore, in the same manner as the reflecting surface already described.

72. If either the reflecting surface or the crystal, placed under the necessary conditions, be carried round a polarised ray, A′ B′ C′ D′, so as to be successively presented to all sides of it, the ray will be completely reflected or transmitted when it is presented to *a′*, the middle of the side A′ B′. As it is moved from *a′* towards *b′*, the quantity of light reflected or transmitted will be less and less, until it comes to *b′*, when none will be reflected or transmitted, the ray being wholly extinguished. As it is moved from *b′* to *c′*, the light reflected or transmitted, small in quantity at first, will be continually greater and greater until it comes to *c′* the middle of C′ D′, when the ray will be wholly reflected or transmitted. As it is moved from *c′* towards *d′*, the quantity of light reflected or transmitted is less and less, until arriving at *d′* the ray is altogether extinguished. After passing from *d′* towards *a′*, the light reflected, at first small, is more and more in quantity until it comes in fine to *a′*, when the ray is, as at first, wholly reflected or transmitted.

73. An instrument adapted to show the effects of polarised light upon bodies on which it is incident or through which it is transmitted, is called a POLARISCOPE, fig. 35, p. 65, and a polarising microscope or MICRO-POLARISCOPE, is a microscope by which the observer is enabled to project polarised light upon the objects, and to observe its effects when transmitted or reflected by them.

Micro-polariscopes have been constructed in various forms, some depending on polarisation by reflection, and some on polarisation by transmission.

One of the most simple and most generally useful, consists of two prisms of Iceland-spar, one of which, P, is placed under the stage, so that the light by which the object is illuminated must previously pass through it, and the other P′ is placed in the body of the instrument between the object-glass and the eye-glass, so that before producing the image, the rays must pass through it.

The light proceeding from P, and projected upon the object, being polarised, and received, after passing through the object-glass, by P′, will be wholly or partially transmitted, or altogether extinguished, according to the sides or poles of the ray to which certain faces of the prism are presented. If, therefore, the instrument be so mounted that the prism P′ can be turned round its axis, its faces can be presented successively to all sides of the rays, so that the light will be in a certain position wholly transmitted, and the image will be seen strongly illuminated. When the prism is gradually turned round, the light transmitted will be less and less, until the prism has been turned through a quarter of a revolution, when the light will be wholly extinguished, and the image will disappear. Continuing to turn

the prism, the image will gradually re-appear, at first faintly, and by degrees brighter, until the prism is moved through another quarter of a revolution, when the image will be again seen fully illuminated. Like changes will take place during the other two quarters of a revolution.

Similar effects will be produced if the prism P′ be fixed, and P be turned round its axis. In this case, by moving the polarising prism P round its axis, the polarised ray is made to revolve, because the position of its poles *a′ b′ c′ d′* has always a fixed relation to the faces of the prism P. Since, therefore, the polarised ray revolves, it presents successively all its sides to the prism P′, by which it is accordingly alternately transmitted, and absorbed wholly or partially in the same manner, exactly as if the ray were fixed, and the prism P′ carried round it.

By the appearance and disappearance of the image corresponding with the position of the prism P′, the position or direction of the planes of polarisation A′ C′ and B′ D′ of the polarised ray is known.

These effects will be produced if the objects through which the light is transmitted or by which it is reflected have themselves no polarising influence. But if they have, various other phenomena will ensue, depending on the character and degree of that influence; but whatever it be, the state of the light, which proceeding from the object-glass forms the image, will be ascertained by the prism P′, which is consequently called the *analysing prism*, the other P being denominated the polarising prism.

Various physical characters are thus discovered in the objects submitted to the microscope by determining the optical effects they produce on polarised light, and many striking and beautiful phenomena are developed.

THE MOUNTING OF MICROSCOPES.

74. The methods of mounting microscopes, so as to adapt them to the convenience and the ease of observers, are very various, depending on the purposes to which they are applied, their price, the exigencies of the purchaser, and the skill, taste, and address of the maker.

The qualities which it is desirable to confer upon the stand and mounting of the instrument are simplicity of construction, easy portability, smoothness and precision in the action of all the moving parts, and such combinations as may cause any tremor imparted to the stand to be distributed equally over every part of the mounting. These capital objects are attained very completely in all the mountings of the best makers, British and Foreign.

The most simple, and consequently the cheapest description of mounting, is that in which fewest parts are moveable. The only parts of a compound microscope which are *necessarily* moveable are those by which the instrument is focussed, and the object illuminated. The most simple mechanical expedient for effecting the former is a rack and pinion attached either to the body or the stage, and for the latter the suspension of the reflector upon an horizontal axis, so that it can be inclined at any desired angle to the axis of the body and the stage.

Whatever be the form or disposition of the stand, it is essential that the axis of the object-piece should pass through the centre of the stage, and that the reflector should be so set as to be capable of reflecting light in the direction of this axis. The body is generally a straight tube, the axis of the eye-piece and object-piece being in the same straight line. In the case of instruments mounted after the model of Professor Amici, however, the body consists of a tube having two parts with their axes at right angles, the axis of the object-piece being vertical, while that of the eye-piece is horizontal. In this case, a prism is fixed in the angle of the tube, at an angle of 45° with the axes by which the rays proceeding vertically from the object-piece are reflected horizontally to the eye-piece, on the principle already explained (30).

75. One of the most simple models for the mounting of a compound microscope was contrived by Frauenhoffer so early as 1816, long before achromatic lenses were produced. This model, owing to its great simplicity, convenience, and cheapness, is still extensively used for the lower priced instruments, especially by the continental makers.

The body of the instrument is attached to a vertical pillar, fig. 36, p. 49, and its axis is permanently vertical. It is focussed by a rack and pinion, worked by a milled head on the right of the observer. The stage is fixed in its position, and placed on the top of a short tube, in the lower part of which the reflector is suspended on an horizontal axis, so that it can be placed at any desired obliquity to the axis of the instrument, and thus can always throw a beam of light upwards to the object. One side of this mirror is concave, and the other plane.

For the illumination of opaque objects, a lens is attached by a jointed arm to the upper part of the pillar, on which the instrument is supported.

M. Lerebours, of Paris, makes excellent microscopes on this model, with a triple achromatic object-piece and other accessories, which he sells at the very moderate price of 90 francs (3*l*. 12*s*.). Several thousands of these have been sold.

76. The attitude of an observer stooping the head to view an object in a microscope, whose eye-piece is vertical, is found to be attended with much inconvenience, especially if the observation be long continued. This has constituted the ground of a very general objection to vertical microscopes. Nevertheless there are many cases in which it would be inconvenient to place the stage in an inclined or vertical position, as, for example, when observations are made on liquids. In all such cases the model of Amici's stand presents obvious advantages, the observer looking horizontally, while the axis of the object-piece is vertical, and consequently the stage horizontal.

Most of the better class of instruments, however, are so mounted that any direction whatever can be given to the axis of the body. Various mechanical expedients are used for accomplishing this, most of which are analogous to the methods of mounting telescopes. In some, the instrument with its appendages is supported upon two uprights of equal height by means of trunnions, which pass through its centre of gravity, so that it turns upon its supports like a transit instrument, the axis of the body being capable of assuming any inclination to the vertical. The observer, therefore, may at pleasure look obliquely or vertically downwards, or obliquely upwards, as may suit his purpose.

Similar motions are also produced by mounting the instrument upon a single pillar by means either of a cradle-joint, such as is generally used for telescope-stands, or a ball and socket. Stands of this form are attended with the advantages of offering greater facility for moving the instrument horizontally round its axis.

In the attainment of all these objects, as well as in the production of eye-pieces and object-pieces of capital excellence, the leading makers of London, Paris, Berlin, and Vienna, have honourably rivalled each other, and it may be most truly said, to their credit, that if some have excelled others in particular parts of the instrument, there is not one who has not in some way or other contributed by invention or contrivance to the perfection either of the optical or mechanical parts.

Much however is also due to the eminent philosophers and professors who have more especially devoted their attention to those parts of science in which the microscope is a necessary means of observation, and foremost among these is the patriarch of optical science, Sir David Brewster. It would be difficult to name the part of the instrument, or of its accessories or appendages, for the improvement of which we are not deeply indebted to this eminent man. Among the more recent philosophers who have contributed to the advancement of micrography, and by whose researches and suggestions the makers have been guided,

may be mentioned Messrs. Goring, Lister, Coddington, Quecket, Mandl, Dujardin, Le Baillif, Seguier, De la Rue, and numerous others.

The eminent makers of the British and Continental capitals are well known. Good instruments of the low-priced sort are made by nearly all the opticians; but those who have more especially devoted their labours to the microscope, are Messrs. Ross, Smith and Beck, Powell and Lealand, Pritchard, Varley, and Pillisdier, in London; Messrs. Nachet, Charles Chevalier and George Oberhauser, of Paris; MM. Ploessel and Schieck, of Vienna; and M. Pistor, of Berlin.

Without the intention of assigning any relative precedence to these artists, we shall now present a brief description of some of the instruments, according as they are severally mounted by them.

CHEVALIER'S UNIVERSAL MICROSCOPE.

77. The mounting of this instrument has always appeared to me to offer as many conveniences and advantages to the observer as can be combined in such an apparatus.

A mahogany case A, fig. 37, p. 1, containing a drawer B, in which the instrument and its appendages are packed when out of use, serves as its support. A strong brass pillar, C C, is firmly screwed into the top of the case, and upon this pillar the entire instrument is supported.

The pillar C C sometimes is made in two lengths, which are screwed one upon the other, by which means the height of the instrument may be varied at pleasure, either one or both lengths being used.

An arm E *c* is attached by a joint at E to the summit of the pillar C C, so that it can be moved on the joint E with a hinge motion, and may thus be placed at any angle with the pillar C C. In the figure it is represented at right angles with C C.

To the middle D of the arm E *c*, a square brass bar D F G is attached at right angles to E *c*, so that when E *c* is at right angles to C C, the bar D F G is parallel to C C. In the face of the bar D F G, which is presented to C C, a rack is cut.

Two square pieces P and M are fitted to the bar D F G, and are moved at pleasure upwards and downwards upon it by means of pinions, having milled heads O and N.

To the square piece P is attached the stage Z, upon which the object is placed, and maintained in its position by two springs, one of which is shown in the figure. This stage is provided with several adjustments, which have been already explained (31 *et seq.*). It will be sufficient for the present to observe that it is capable of being moved upwards and downwards with the

square piece P, to which it is attached by turning the milled head O, and that a slower motion, to give more exact adjustment, is imparted to it by a fine screw having a milled head at Q.

To the square piece M is attached the illuminator H, on one side, K, of which is a concave reflector, and on the other, I, a smaller plane reflector. This illuminator has two motions, a horizontal or lateral one upon a joint at M, by which it can be placed at pleasure either vertically under the centre of the stage Z, or at a limited distance on one side or other of the vertical through the centre of the stage. The circular illuminator is suspended at two points diametrically opposite in a semicircular piece, and may be placed at any desired inclination to the vertical, and with either reflector upwards by means of the milled head I.

From the lowest part of the pillar C C a piece projects, having a cavity corresponding with the size and form of the bar D F G, into which that bar enters when it is vertical as represented in the figure, and in which it is held by the pin at G.

The body of the microscope, as shown in the figure, is rectangular. The eye-tube T is moved backwards and forwards in the body R by a pinion U working in a rack. The eye-piece S is inserted in this tube, and the eye is protected from the light by a circular blackened screen, seen edgeways in the figure. The rectangular tube V X is inserted by a bayonet-joint in the remote end of the body R, in which it is capable of being turned, so that the object-tube X shall be horizontal, to enable the observer with greater facility to screw on or to change the object-glasses at Y.

The body is attached to the bar E *c* by a joint at *c*, upon which it can be turned, by which means other positions can be given to the instrument, as will presently be explained.

An assortment of object-glasses is supplied, which may be screwed at pleasure upon Y. They are adapted to each other in sets of three, so that one, two, or three may be attached to Y according to the power required.

In the angle *b* of the body, a rectangular prism is fixed, by which the rays proceeding upwards from Y are reflected horizontally along the axis of R to the eye-piece, on the principle explained in 30.

Several eye-pieces of different powers are supplied with the instrument.

The magnifying power may be varied within certain narrow limits by moving the eye-tube in or out by the pinion U, and at the same time adjusting the focus by the pinions O and Q, which move the stage Z. When it is desired to augment the power, the

tube T is drawn out so as to lengthen the body, and the stage Z is brought nearer to the object-glass Y. The effect of this is to increase the dimensions of the optical image produced in the eye-piece by the object and field glasses, as explained in 6.

If a greater increase of magnifying power be desired, the eye-piece may be withdrawn, and a shorter one substituted for it.

But these expedients are only useful when the increase of power required is confined within comparatively narrow limits. All greater amplification must be produced by the object-glasses. These, as has been explained, are made in sets of three, having different powers. The lowest power will be obtained by screwing the first lens only of the lowest set upon Y; the next by screwing on the second; and the next by screwing on the third; by which the powers of all the three will be combined.

If it be desired to obtain a still higher power, these lenses being taken off, the first lens of the set next in order is screwed on, then the second, and in fine the third, by which another series of three increasing powers is obtained.

In this manner, by a suitable assortment of object-glasses and eye-pieces, any desired degree of amplification can be obtained.

The height of the case A and the length of the pillar C C are so arranged, that when the case is placed upon a table of the usual height, the eye of an observer of average height when seated will be on a level with the eye-piece S.

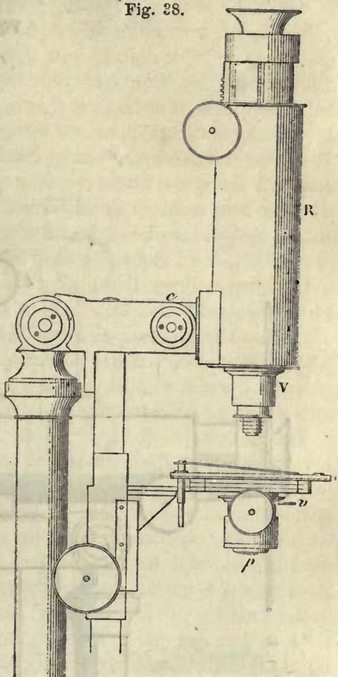
When the observer is about to submit an object to examination, having mounted the instrument, placed it firmly upon a table with an even surface so as to prevent any rocking or instability, and regulated the height of his seat so that his eye shall be at the level of the eye-piece, he selects an eye-piece and object-glasses having a suitable magnifying power, and in doing this it is most important to commence with a low power, to be gradually increased. For this purpose, one object-glass of a set is first screwed on, after which two, and in fine three, are used.

In this manner a survey is taken of the general outline and larger parts in the first instance, and the more minute parts afterwards.

78. The most generally convenient position for the instrument is that which is shown in fig. 37. If a vertical position be desired, it may however be easily obtained. For this purpose the rectangular piece V is drawn out of the bayonet-joint, and the object-tube is directly inserted in the body, so that its axis shall be horizontal and coincident with that of the body R and the eye-tube T. The body is then turned upon the joint *c* until it is raised into the vertical position. The relative position which the parts then assume is that which is shown in fig. 38.

79. When chemical phenomena are submitted to microscopic examination, and in general when liquids are observed which are liable to evaporation, it is found inconvenient to place the stage under the object-glass, inasmuch as the vapour proceeding from the liquid being more or less condensed upon it, destroys the clearness of the image.

Fig. 38.



Acid vapours sometimes rise from the substances under experiment, which often tarnish the object-glasses, and almost always corrode the metal of the instrument.

In such cases, therefore, it is necessary to provide means to place the liquid under observation in a glass capsule (a watch-glass, for example) above the object-glass, which must consequently be directed upwards, the stage supporting the capsule being over it.

To accomplish this, the rectangular piece V X is turned within the body upon its bayonet-joint through half a circumference, so that the object-tube X is presented vertically upwards, as shown in fig. 39. The arm *e f* carrying the stage *l*, the diaphragm *h* to limit the illumination, and the illuminating reflector or lens *g*, is then fixed upon the tube X; these pieces being severally moveable on the bar *e f* in the manner already described.

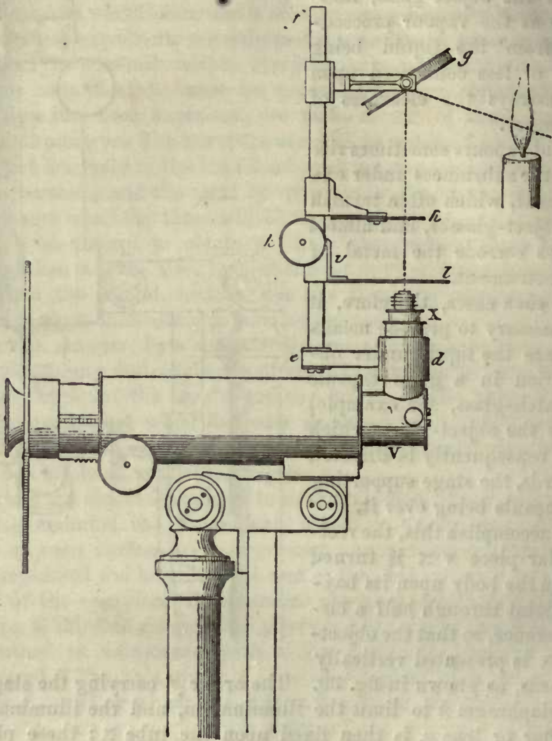
This arrangement is also useful when it is required to observe minute bodies which sink to the bottom of liquids, or animalcules which rarely come near the surface.

In certain cases, also, the circulation of the blood can only be observed with the instrument in this position.

80. It is sometimes desirable to direct the instrument horizontally towards the stage placed vertically. To accomplish this, it is only necessary, after arranging the instrument as shown in fig. 40, to turn the arm E *c* round through an angle of

90°, the pin G being withdrawn, so as to leave the bar D F G with the stage and its appendages free to turn on the joint E with the arm E *c*. The body R and the bar D F G will then be brought

Fig. 39.



into the horizontal position. The stage will then be vertical, and the object will be held in its position by the springs.

The illumination of the object may be produced either by the reflector or lens in the manner already described; or, if they are removed from the bar D F G, the stage may be presented directly to the light of the sun, the clouds, or a candle or lamp.

In some cases, however, when it is necessary to obtain a more intense illumination, an apparatus represented at *s s'* is employed, consisting of two convex lenses placed in the ends of a conical tube which slides upon the bar, by means of a square piece at the end of the arm *t*.

Besides the several motions above described, the body of the instrument has motion in an horizontal plane round the piece *a*,

Fig. 40.

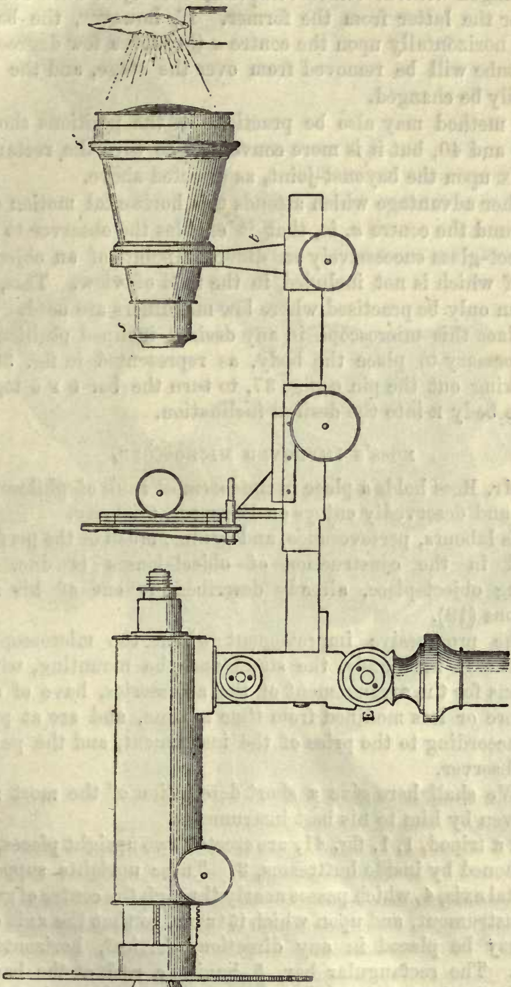


fig. 37, as a centre. This motion is very convenient when the instrument is used in the positions shown in figs. 37, 38, and 39,

for the purpose of changing the angles. In general, and more especially when high powers are used, the object-glasses are so close to the stage, that they cannot be conveniently unscrewed and changed without either removing the object-tube from the stage, or the latter from the former. If, however, the body be turned horizontally upon the centre *a* through a few degrees, the object-tube will be removed from over the stage, and the lenses can easily be changed.

This method may also be practised in the positions shown in figs. 38 and 40, but it is more convenient to turn the rectangular piece Y X upon the bayonet-joint, as directed above.

Another advantage which attends this horizontal motion of the body round the centre *a*, is, that it enables the observer to direct the object-glass successively on different points of an object, the whole of which is not included in the field of view. This, however, can only be practised where low magnifiers are used.

To place this microscope in any desired inclined position, it is only necessary to place the body, as represented in fig. 38, and then taking out the pin G, fig. 37, to turn the bar D F G together with the body R into the desired inclination.

ROSS'S IMPROVED MICROSCOPE.

81. Mr. Ross holds a place in the foremost rank of philosophical artists, and deservedly enjoys an European celebrity.

To his labours, perseverance, and genius, much of the perfection attained in the construction of object-lenses is due. The adjusting object-piece, already described, is one of his recent inventions (19).

In the progressive improvement which the microscope has undergone in his hands, the stand and the mounting, with the provisions for the arrangement of the accessories, have of course been more or less modified from time to time, and are at present varied according to the price of the instrument, and the purposes of the observer.

82. We shall here give a short description of the most recent form given by him to his best instruments.

Upon a tripod, 1, 1, fig. 41, are erected two upright pieces, 2, 2, strengthened by inside buttresses, 3. These uprights support an horizontal axis, 4, which passes nearly through the centre of gravity of the instrument, and upon which it turns, so that the axis of the body may be placed in any direction, vertical, horizontal, or oblique. The rectangular bar, 5, having a rack at the back, is moved in the box, 6, by the pinion, 7. The body, 8, is inserted in a ring at the end of the arm, 9, which latter is fixed upon a pin at the end of the rod, 5, upon which it turns, so as to remove

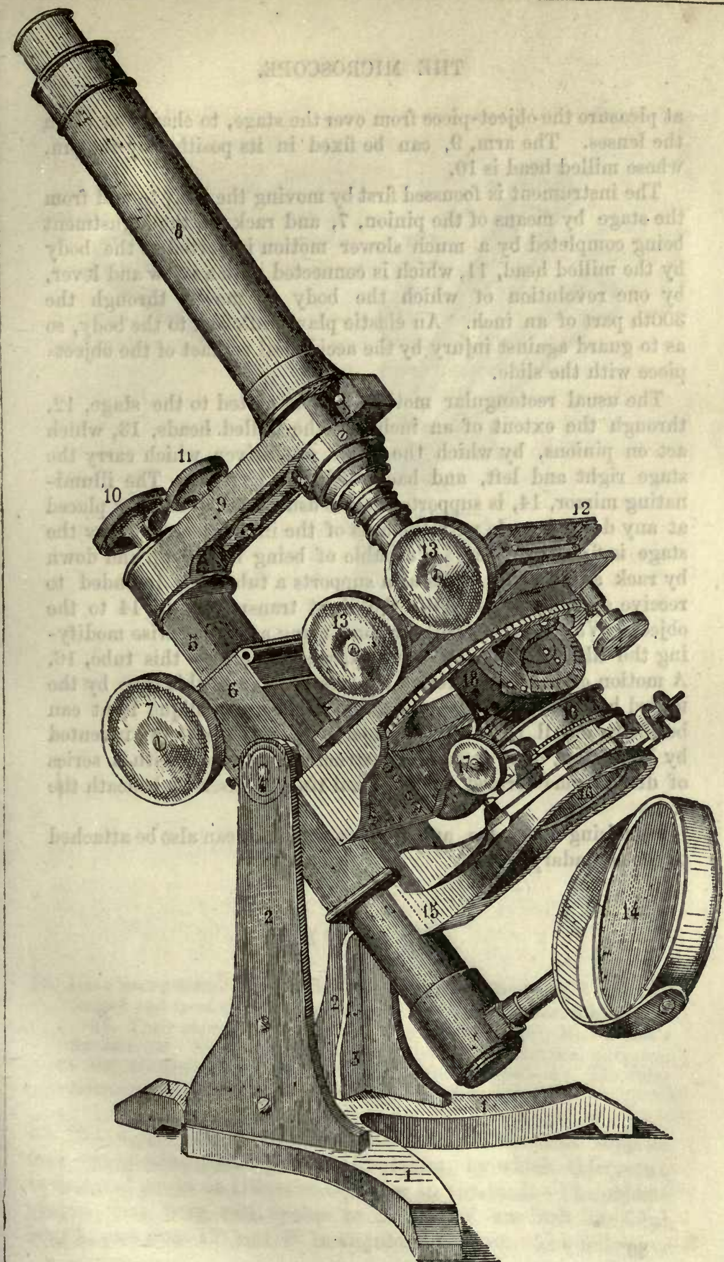


Fig. 41.

at pleasure the object-piece from over the stage, to change or clean the lenses. The arm, 9, can be fixed in its position by the pin, whose milled head is 10.

The instrument is focussed first by moving the body to and from the stage by means of the pinion, 7, and rack, 5, the adjustment being completed by a much slower motion imparted to the body by the milled head, 11, which is connected with a screw and lever, by one revolution of which the body is moved through the 300th part of an inch. An elastic play is allowed to the body, so as to guard against injury by the accidental contact of the object-piece with the slide.

The usual rectangular motions are imparted to the stage, 12, through the extent of an inch, by the milled heads, 13, which act on pinions, by which the racks are driven which carry the stage right and left, and backward and forward. The illuminating mirror, 14, is supported in the usual way, so as to be placed at any desired angle with the axis of the instrument. Below the stage is fixed an arm, 15, capable of being moved up and down by rack and pinion. This arm supports a tube, 16, intended to receive apparatus to modify the light transmitted by 14 to the object. Various apparatus for condensing and otherwise modifying the illumination are provided, which fit into this tube, 16. A motion of revolution round its axis is given to this tube by the milled head, 17. By these means, the effect of oblique light can be shown on all parts of the object. A condenser, 18, invented by Mr. Gillet, of a peculiar construction, provided with a series of diaphragms formed in a conical ring, is inserted beneath the stage.

Polarising apparatus, and other appendages, can also be attached to the secondary stage.

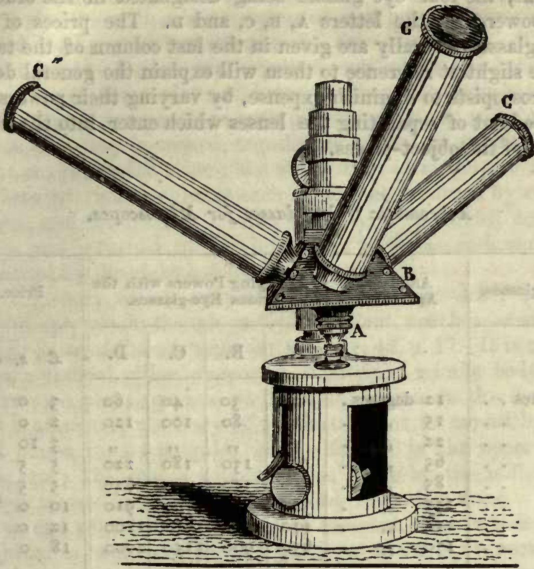


Fig. 45.—NACHET'S TRIPLE MICROSCOPE.

THE MICROSCOPE.

CHAPTER VI.

83. His object-glasses. MESSRS. SMITH AND BECK'S MICROSCOPE : 84. Their largest and most efficient instrument.—85. Their smaller microscope. —86. Their object-glasses.—87. Varley's microscope. M. NACHET'S MICROSCOPE : 88. Their adaptation to medical and chemical purposes. —89. Multiple microscopes.—90. Double microscope.—91. Binocular microscope.—92. Triple and quadruple microscopes.

83. WITH his largest and best instruments, Mr. Ross supplies four eye-glasses and eight object-glasses, by which thirty-two varieties of power and illumination may be obtained. The object-glasses vary from two inches to a 12th of an inch in focal length, and from 12° to 170° in angular aperture. The following

is a tabulated statement of the powers resulting from these combinations, the four eye-glasses being designated in the order of their powers, by the letters A, B, C, and D. The prices of the object-glasses severally are given in the last column of the table, and the slightest reference to them will explain the general desire of microscopists to diminish expense, by varying their powers, by the expedient of separating the lenses which enter into the composition of the object-pieces.

Achromatic Object-glasses for Microscopes.

Object-glasses.	Angular Aperture.	Magnifying Powers with the various Eye-glasses.				Price.		
		A.	B.	C.	D.	£	s.	d.
2 inches . .	12 degrees.	20	30	40	60	3	0	0
1 ,, . .	15 ,, .	60	80	100	120	2	0	0
1 ,, . .	22 ,, .	,,	,,	,,	,,	3	10	0
$\frac{1}{2}$,, . .	65 ,, .	100	130	180	220	5	5	0
$\frac{1}{4}$,, . .	85 ,, .	220	350	500	620	5	5	0
$\frac{1}{6}$,, . .	135 ,, .	320	510	700	910	10	0	0
$\frac{1}{8}$,, . .	150 ,, .	420	670	900	1200	12	0	0
$\frac{1}{12}$,, . .	170 ,, .	650	900	1250	2000	18	0	0

When angular apertures, so extreme as those indicated in the preceding table, are attempted, it is necessary that the object-lens presented to the pencil diverging from the object, shall be of the meniscus form, the concave side being turned towards the object, for the reasons explained in 19.

Besides the larger class of instruments above described, Mr. Ross constructs microscopes in a variety of other forms, which are placed within the reach of those who do not find it convenient to incur the expense of the larger instrument.

MESSRS. SMITH AND BECK'S MICROSCOPE.

84. The largest and most efficient class of instruments constructed by these artists, do not differ much in their mounting from those of Mr. Ross above described. Like the latter, they are supported by a horizontal axis, between two strong vertical pillars, screwed into a tripod base. The instrument with its appendages, turning on the horizontal axis, can thus be placed at any obliquity whatever with the vertical. The coarse adjustment of this microscope is made by a rack and pinion, by which

the entire body is moved to and from the stage. The object-piece is set in a tube, which moves within the principal tube of the body, the motion being imparted to it by a fine screw with a milled head, which constitutes the fine adjustment. Two different kinds of stage are supplied, one called the lever stage, consisting of three plates of brass, the lowest of which is fixed, and the other two provided with guides and slides, and a lever by which they may be moved, together or separately, in directions at right angles to each other; the other form of stage also has two motions at right angles to each other, one produced by rack and pinion, and the other by a screw whose axis is carried across the stage, and is turned by the left hand, while the rack and pinion is turned by the right hand.

85. Messrs. Smith and Beck also construct other forms of microscope, which, though perfectly efficient, are cheaper and more simple; one of these is represented in fig. 42, p. 17. It is mounted upon a vertical pillar, supported on a tripod T; the body of the microscope plays upon a cradle joint, to which the bent arm U U is attached; the body of the instrument is moved by a rack and pinion in a triangular groove formed in the upper part of this arm; the coarse adjustment is made by the milled heads which move the entire body to and from the stage. In the lower end of the body, a tube is inserted, from which an arm projects, in which a fine screw plays, which is connected with another arm attached to the body of the instrument: by turning the milled head, a slow motion is therefore imparted to the tube thus inserted in the lower extremity of the body. In the end of this tube the object-piece is set, so that the fine adjustment is made by this screw.

To the lower end of the bent arm U U, the stage and its appendages are attached; two motions at right angles to each other are imparted to the stage, by milled heads; the reflector is mounted in the usual way, and provisions are made under the stage, by which achromatic condensers, polarisers, and other apparatus can be applied; the disc of diaphragms is shown at L; it is mounted on a short piece of tube, in which polarising and other apparatus may be inserted.

86. Messrs. Smith and Beck supply with their best microscopes three eye-pieces and five object-pieces, the powers of which, as well as their angles of aperture, are indicated with their prices in the annexed table.

Achromatic Object-glasses for the Microscope.

Focal length.	Linear Magnifying Power nearly.*	With Eye-pieces. No.1.	No.2.	No.3.	Angle of aperture about	Price. £	s.	d.	Licoerkuhn additional. s.
$1\frac{1}{2}$ inch	Draw-tube closed	20	45	80	13 degs.	3	0	0	15
	Add for each inch of tube drawn out	4	6	8					
$\frac{2}{3}$ inch	Tube closed . .	60	105	180	27 degs.	3	3	0	11
	Add for each inch of tube . . .	7	12	20					
$\frac{4}{10}$ inch	Tube closed . .	120	210	350	55 degs.	5	5	0	10
	Add for each inch of tube . . .	12	20	35					
Ditto	Ditto . . .	do.	do.	do.	65 degs.	6	6	0	10
Ditto	Ditto . . .	do.	do.	do.	75 degs.	7	7	0	10
$\frac{1}{5}$ inch	Tube closed . .	240	430	720	85 degs.	6	6	0	
	Add for each inch of tube . . .	30	45	80					
Ditto	Ditto . . .	do.	do.	do.	100 degs.	7	7	0	
$\frac{1}{8}$ inch	Tube closed . .	450	760	1300	100 degs.	8	8	0	
	Add for each inch of tube . . .	40	60	115					
Ditto	Ditto . . .	do.	do.	do.	120 degs.	10	10	0	

* With the $\frac{2}{3}$ inch object-glass and the erecting-glasses, employing eye-pieces Nos. 1 and 2, the magnifying power will range from 5 to 150.

Among the accessories of the microscope due to Messrs. Smith and Beck, we must not omit to mention the microscope-table, contrived to facilitate the observations of several persons directed to the same object with the same microscope. Every one who has used this instrument is aware how fatiguing it is to several persons to succeed one another in observing with the same instrument. They are obliged constantly to shift their position, and consequently to make their observation standing. The microscope-table, if it do not entirely remove this inconvenience, greatly diminishes it. It is a circular table, firmly supported on a pillar and claw, capable of being turned with a smooth motion round its centre in its own plane. The observers sitting round it, the microscope is moved successively to the position occupied by each of them by merely turning the table. The best sort of

these tables are made with a plate-glass top, and surrounded by drawers, in which the apparatus can be conveniently assorted.

MR. VARLEY'S MICROSCOPE.

87. This artist has constructed instruments with provisions similar to those already described; they are somewhat different in their form and details. He has, however, recently introduced a microscope, which claims the advantage of enabling the observer to examine living objects, such as animalcules, notwithstanding the inconvenience arising from their restless mobility, causing them continually to escape from the field of view. The stage motion with its appendages, contrived by Mr. Varley, enables the observer, without difficulty, to pursue the object.

He has also contrived a phial-microscope, by which aquatic plants and animals can be conveniently observed.

M. NACHET'S MICROSCOPES.

88. M. Nachet, of Paris, has acquired an European celebrity for the excellence of his instruments, and for the various inventions and improvements in their construction, by which he has extended their utility. He has constructed instruments in various forms, according to the uses to which they are to be applied and their price. For medical and chemical purposes, the body of the microscope slides in a vertical tube, the coarse adjustment being made by a rack and pinion, and the fine by a screw. The stage is firmly fixed under the object-piece, at the top of a hollow cylinder, within which the illuminating apparatus and other appendages are included.

89. One of the most recent novelties due to this eminent artist, is a form of microscope by which two or more observers may, at the same time, view the same object, thus conferring upon the common microscope a part of the advantages which attend the solar microscope. This is accomplished by connecting two or more tubes, each containing its own eye-piece, with a single tube containing an object-piece; it has been already shown that the axis of the tube containing the eye-piece may be placed at any desired inclination, with that which contains the object-piece, by placing in the angle formed by the two tubes, a reflector, or reflecting prism, in such a position, that the pencils of rays proceeding from the object-piece shall be reflected to the eye-piece, without otherwise deranging them. It is evident, therefore, that if the rays proceeding from the object-piece could be at the same time received by two or more reflectors, so placed as to reflect them in two or more directions, they might be transmitted along two or more tubes in these directions to two or more eye-pieces, through which the same object might thus be viewed at

the same time, and through the same object-piece by two or more different observers.

Such is the principle upon which the multocular microscope of M. Nachet is based.

90. A double instrument of this description is shown in fig. 43, where A is the object-piece directed vertically downwards on the stage; above it is a case, containing a triangular prism which is so formed that the light reflected from its left side shall pass along the axis of the right-hand tube, and that reflected from its right side along the axis of the left-hand tube. Observers looking into eye-glasses set in these tubes, would therefore both see the same object in precisely the same manner.

It may perhaps be objected, that the focus which would suit the eye of one observer, would not suit the other; the difference, however, between the focal adjustments of different eyes is always so inconsiderable, that it can be equalised by a small motion given to the tubes carrying the eye-pieces.

Microscopes, as they are usually mounted, reverse the objects, the top appearing at the bottom, the right at the left, and *vice versâ*. This being found inconvenient in instruments used for dissection, where the motion of the hand and the scalpel of the operator would be reversed, expedients are provided by which the

Fig. 43.

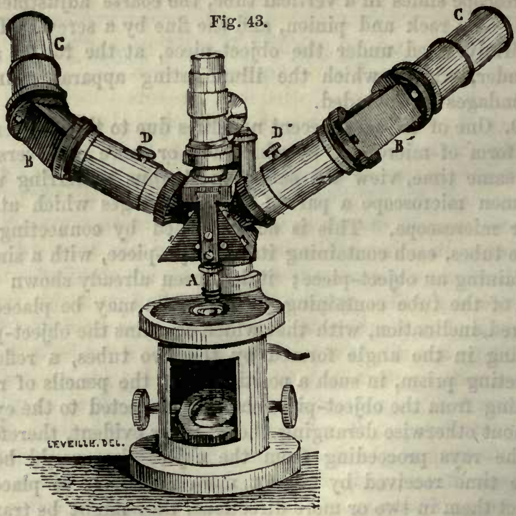
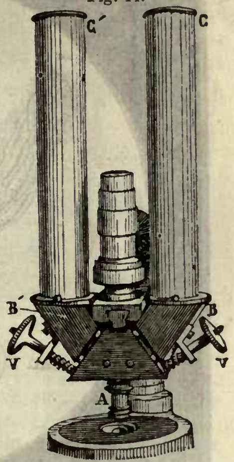


image is redressed, and the object viewed in its natural position. This is accomplished in the microscope represented in fig. 43, by

two prisms fixed at B B′ in the tubes, which are placed at right angles to the lower prism A; by this second reflection, the reversed image of the first reflection, being again reversed, is made to correspond with the natural position of the object.

Fig. 44.



91. An interesting variety of this form of instrument, which may be called a BINOCULAR MICROSCOPE, is shown in fig. 44. In this case the two tubes, B C and B′ C′, containing the two eye-pieces, are placed parallel to each other, the distance between them being regulated by the screws V V; if this distance be so adjusted as to correspond with the distance between the eyes of the same individual, the microscope may be used with both eyes, in the same manner as a double opera-glass. This has the advantage of giving a stronger appearance of relief to the objects viewed, which is especially desirable for a certain class of objects, such as crystals.

92. A triple microscope, upon the principle above described, is shown in fig. 45, p. 81, where A is the object-piece, B the multiple prism, and C, C′ and C″ the three eye-tubes.

A similar instrument, with four eye-tubes, including figures to illustrate the mode of observing with it, is shown in fig. 46, p. 33.

One of the advantages of this class of instruments is, that a professor and one or more of his pupils may view the process of a microscopic dissection which with a common microscope would be impossible, and to which the solar microscope would be inapplicable. Microscopic dissections, in general, can only be exhibited to those who do not execute them, by their ultimate results. Any phenomena which are developed in their progress, can only be made known to others by description; and it is not necessary to say, how imperfect such a mode of communication must be, compared with direct observation.

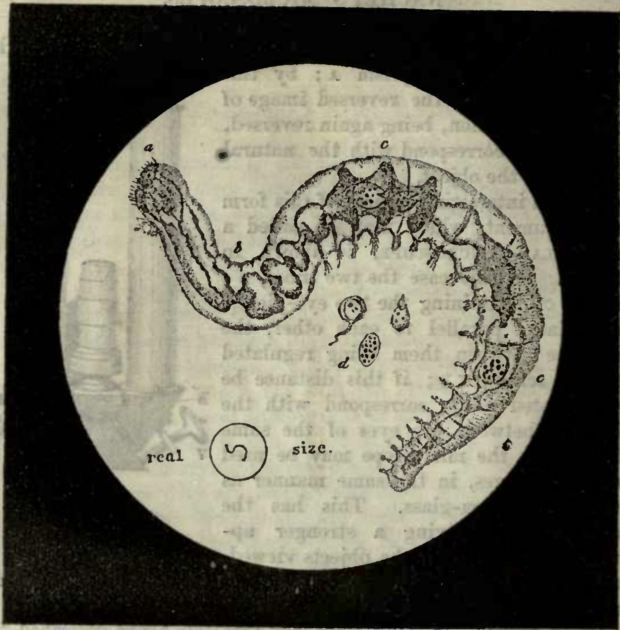


Fig. 5.—MAGNIFIED VIEW OF THE LURCO OR GLUTTON.

MICROSCOPIC OBJECTS.

1. Microscopic objects.—2. The dragon-fly and its larvæ.—3. The satyr. —4. The linceus sphericus.—5. The lurco, or glutton.—6. The water-fly.

1. Having in the preceding Tract explained the structure, application, and use of the microscope in the various forms which have been given to that instrument, we shall here briefly notice a few remarkable microscopic objects, selected chiefly from the Microscopic Cabinet of Mr. Pritchard, illustrated with magnified drawings by the late Dr. Goring.

2. The family Libellulidæ includes an extensive and beautiful group of large insects not sensibly differing in their external form from the ant-lion, already noticed.*

* Instinct and Intelligence, p. 119.

These are popularly known by the names of horse-stingers and dragon-flies. The former name is founded on a vulgar error, since the animal has no sting. The illusion implied by the latter is, however, more correct, since the insects, both in their appearance and voracious habits, are certainly more entitled to the name of dragons than that of demoiselles, or lady-flies, by which they are commonly known in France.

Fig. 1.

The beautiful appearance of these insects on the wing, their varied colours, the gauze-like structure of their wings, and the rapidity of their flight, must have attracted general attention. In hot summer days, they may be seen darting backwards and forwards in the air over standing pools, which supply them abundantly with the insects on which they feed. Their colours are subject to much diversity, the males having an abdomen of leadish blue, while that of the females is a yellowish brown. In some species, the males have a rich bright blue colour, with black wings, while the females are distinguished by a fine green, with colourless wings.

After impregnation, the female hovers over the surface of the water until she selects a place for the deposition of her eggs, which she deposits one by one in the water, beating the surface with her tail while she lays them, until at length they are collected into a mass resembling a bunch of grapes.

The larvæ on issuing from the egg are so minute as to be scarcely perceptible to the naked eye. In some days, however, they attain the length of the tenth of an inch, and cast their skin for the first time. To the naked eye they appear in this state like black spots, to which a tail is attached. When well fed they grow rapidly; and when they have attained the length of about a quarter of an inch, they begin to display their characteristic courage and ferocity, attacking, with open mouth, creatures ten times their own bulk; and, when pressed by hunger, devouring each other.

The magnified drawing of this larva, from which fig. 2 was

Fig. 2.—MAGNIFIED VIEW OF THE LARVA OF A SPECIES OF DRAGON-FLY DRAWN BY DR. GORING.

taken, was made by Dr. Goring, and published with a description

by Mr. Pritchard in the Microscopic Cabinet. The real length of the creature, measured from the extremity of the antennæ to that of the tail, was eight-tenths of an inch. It is represented in the figure, as seen in profile, the breadth of the head and other parts being necessarily foreshortened.

A system of tracheæ, with numerous ramifications, passes along each side of the body from the head to the tail, one of which is seen in the figure. These respiratory apparatus ramify in a beautiful manner in the triple branches of the tail, each of which receives a branch from each trachea.

During its growth the larva casts its skin several times, and the skin which it thus throws off, being translucent, is an interesting and beautiful microscopic object.

The eyes as well in the larva as in the perfect insect are very salient, and from their magnitude and structure form interesting microscopic objects. Like those of some other insects described in a former Tract,* they consist of a multitude of distinct organs of vision, each of which is an hexagonal lens. It was observed by Latreille, that their number increased in proportion to the voracity of the insect. Leuwenhoeck counted 12000 in a single insect. Each hexagon is a convergent lens, which may be converted into a microscope. Each of these lenses is found to produce an inverted image of an object to which it is presented.

3. The object shown in fig. 3, engraved from a drawing by Dr. Goring, and described in the Microscopic Cabinet by Mr. Pritchard, belongs to the class of animalcules denominated by Müller monoculi, from the circumstance of their having a single organ of vision, *a*, placed in the centre of the front of the head. This specimen is called the satyr, and is the amymone satyr of Müller. The figure represents a magnified view of the full-grown insect, seen at the inferior surface of its body as it presents itself to the observer, attached to the inner surface of a vase of water in which it moves. The real length of the animalcule here represented was the 120th of an inch. When they are

Fig. 3.

* "Microscopic Drawing and Engraving," p. 50.

young they are much smaller, and being then perfectly translucent, are highly interesting microscopic objects. They are found in abundance in the months of March and April, at the surface of shallow pools of clear water which contain aquatic plants.

The back of this animalcule is protected by a tender and transparent shell, the belly being naked and membranous. Seen in profile it resembles a tortoise, but, as shown in the figure, it has the form of a horse-shoe. It has four feet, and two antennæ attached to the inferior part of the body, and radiating from a common centre. Placed in the middle of the head, between the two antennæ, *b*, are the mouth and the single eye, *a*, the latter being black, and set in a square orbit of a deep crimson colour. Each of the antennæ has four articulations, and is furnished with bristles at its extremity. The feet, *c c*, are divided at the second joint, and terminate in strong pincers. The peristaltic motion of the alimentary canal can be distinctly perceived with the microscope, by observing the dark lines which run along the body of the animalcule. On each side of this canal are placed the ovaries, *d*, which, when they are fully developed, are distinguished by their dark colour. The satyr swims by sudden impulses, moving the feet rapidly, and sometimes appears to slide along the internal surface of the vase.

4. The animalcule represented in fig. 4, and reproduced from a drawing by Dr. Goring, is the linceus sphericus of Müller, miscalled monoculus minutus by Linnæus, since it has two eyes sufficiently apparent. The figure is reproduced from the Microscopic Cabinet of Mr. Pritchard, where the animalcule is described.

Fig. 4.

The shell or cuirass, which is quite translucent, consists of a single piece, without any perceptible articulation. It possesses, however, sufficient elasticity to allow the animal to open it at will, after the manner of a common mussel. The two edges of the opening are seen in the figure at *a*, the figure being understood to present a profile of the object. The two eyes, *a*, have different magnitudes, and their black colour presents a striking

contrast with the surrounding parts. They are encased in the shell by which they are protected. The beak, *b*, is pointed, and participates in the general convexity of the shell. Under it is placed a second beak-like projection, somewhat shorter, and having three coarse hairs at its extremity, which probably serve the purpose of palpi or feelers. Below this are placed the two antennæ, *c*, each of which is terminated by similar but longer hairs. The false feet or branchiæ, which are four in number and ranged along the edge of the shell, are covered with hairs, and terminate like the antennæ; by their action a rotatory motion is imparted to the animalcule, which is accelerated by the action of the projecting part, *d*, against the water. This part is ciliated on its posterior edge, and armed at its extremity with strong claws. The ovaries, which appear at *e*, have a greenish-blue colour, and the form of a mulberry. The convolutions of the alimentary canal with the food contained in it are visible with the microscope from one extremity to the other.

But the most remarkable organ is a small oval body placed behind the head and shown in the upper part of the figure. This body has a rapid motion of pulsation.

5. These creatures feed upon animalcules, and in their turn become themselves the prey of aquatic larvæ and coleoptera, such as the water-beetles. They are the especial food of the lurco, or glutton (the larva of the naid), a magnified view of which is shown in fig. 5, with several lincei, *c*, visible within it. The young ones are seen playing around the mother, and on the approach of an enemy they rush for protection under her cuirass, which she immediately closes upon them.

6. The crustaceous animalcule represented in B, fig. 1, in its natural size, and in A, fig. 2, magnified, is the four-horned cyclops, or little water-fly; the cyclops quadricornis of Müller, the monoculus quadricornis of Linnæus, and the pediculus aquaticus, or water-louse, of Baker. The figure was drawn by Dr. Goring, and described by Mr. Pritchard in the Microscopic Cabinet.

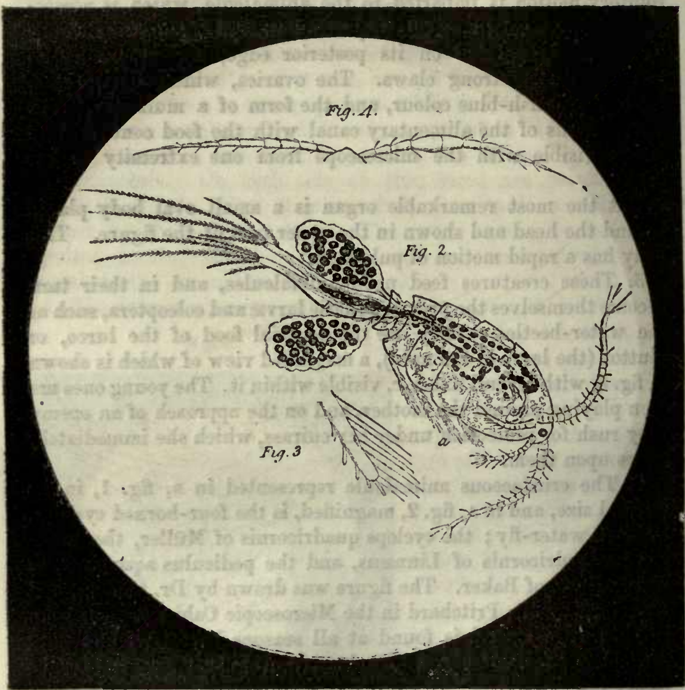
This little animal is found at all seasons in water, but more especially in the months of July and August, when it may be easily taken by a net at the depth of about an inch below the surface.

The body is covered with scales, which have a vertical and lateral motion. Their edges do not meet under the insect, but leave a space for the insertion of the organs of respiration, *a*. The beak is short and pointed, and is a mere prolongation of the first segment of the body. A little above it is inserted in the cuirass a single eye of a crimson colour, so dark as to approach

nearly to black. On each side of the eye are inserted the antennæ, of which there are two pair, the superior being longer than the inferior. They are composed of numerous articulations, from each of which issue two or several hairs. In some species the sexes are distinguished by the form of these appendages, being straight and thicker, with an enlargement towards the middle of their length, in the male, as shown in fig. 4.

These insects move by sudden jumps or plunges, but sometimes creep along the twigs of plants, in which movements they are

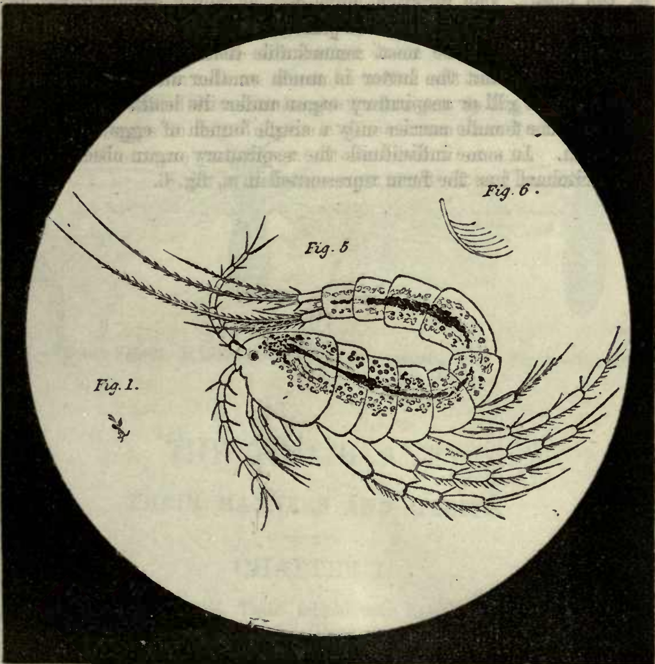
A



aided by their feet or branchiæ. These members are in almost incessant motion, a circumstance which renders the observation of their precise form in the living animal difficult. One of them is represented as seen under a higher magnifying power in A, fig. 3; they are generally transparent, but sometimes have a greenish-blue colour.

The ovaries consist of two sacs, which have the appearance of bunches of grapes attached to either side of the posterior extremity of the body, as shown in A, fig. 2. The eggs are globular, and are enclosed in a transparent membrane. The centre of each egg has an opaque colour, some being green and others red. Their number increases with the age of the female, and when they have attained a sufficient maturity the embryo of the future animal may be seen within them with a magnifier. Mr. Pritchard has distinctly seen these with a single lens with a focal length of about the 25th of an inch. At the extremity of the alimentary canal the tail

B



divides into two portions, whose extremities are fringed with bristles, which present the appearance of splendid plumes.

The alimentary canal and its peristaltic movements are distinctly visible in specimens which are only slightly coloured. Above this canal two others can be observed, through which the eggs are projected to the ovaries at each side of the tail.

The colours of the coat of these insects vary in different individuals, as well as the colours of their ovaries, some being of a greenish-blue, and others red with green ovaries.

Another variety of this, called by Müller the cyclops minutus, or little cyclops, and popularly the jumper, is shown in B, fig. 5, as drawn by Dr. Goring, the animalcule being in a bent position, one of its characteristic attitudes. The real length of this specimen was about the 250th of an inch.

The structure of the coat, or cuirass, is similar to that of the animalcule represented in A, fig. 2, but it has a greater number of segments and a more graceful outline. The single eye is encrusted in the shell. The antennæ have not as many articulations as those of fig. 2, and the inferior pair of palpi is more plumed at the extremities. The most remarkable distinction between the two species is, that the latter is much smaller and supplied with only a single gill or respiratory organ under its beak. It has ten feet, and the female carries only a single bunch of eggs under the abdomen. In some individuals the respiratory organ observed by Mr. Pritchard has the form represented in B, fig. 6.

Fig. 1.—The Termes Embia.

Fig. 2.—The Termes Fatalis, or Bellicosus, with wings folded.

Fig. 3.—Termes Fatalis, or Bellicosus, with wings expanded.

Fig. 4.—The King.

THE WHITE ANTS.

THEIR MANNERS AND HABITS.

CHAPTER I.

1. Their classification.—2. Their mischievous habits.—3. The constitution of their societies. — 4. Chiefly confined to the tropics.—5. Figures of the king and queen.—6. Of the workers and soldiers.—7. Treatment of the king and queen.—8. Habits of the workers.—9. Of the soldiers.—10. The nymphs.—11. Physiological characters.—12. First establishment of a colony.—13. Their use as food and medicine.—14. The election of the king and queen.—15. Their subsequent treatment.—16. The impregnation of the queen.—17. Figure of the pregnant queen.—18. Her vast fertility.—19. Care bestowed upon her eggs by the workers.—20. The royal body-guard.—21. The habitation of the colony.—22. Process of its construction.—23. Its chambers, corridors, and approaches.—24.

Vertical section, showing its internal arrangement.—25. View of these habitations.—26. Contrivances in their construction.—27. Use made of them by the wild cattle.—28. Used to obtain views to seaward.—29. Use of domic summit for the preservation of the colony.—30. Position, form, and arrangement of the royal chamber—its gradual enlargement for the accommodation of the sovereigns.—31. Its doors.—32. The surrounding antechambers and corridors.—33. The nurseries.—34. Their walls and partitions.—35. Their position varied according to the exigencies of the colony.—36. The continual repair and alterations of the habitation.—37. Peculiar mould which coats the walls.—38. The store-rooms for provisions—the inclined paths which approach them—the curious gothic arches which surmount the apartments.—39. The subterranean passages, galleries, and tunnels.—40. The covered ways by which the habitation is approached.—41. The gradients or slopes which regulate these covered ways.—42. The bridges by which they pass from one part of the habitation to another.—43. Reflections on these wonderful works.—44. The tenderness of their bodies render covered ways necessary.—45. When forced to travel above ground they make a covered way—if it be accidentally destroyed they will reconstruct it.

1. Of all the classes of insects which live in organised societies, the most remarkable after the bee are the family Termitinæ, popularly known under the name of white ants, though they have little in common with the ant, except their social character and habits.

Much discordance has prevailed among naturalists respecting their history and classification. They were assigned by Linnæus to the order Aptera, or wingless insects. More exact observation has, however, proved this to be erroneous; since, in the perfect state, they possess membranous wings like those of the dragon-fly, which being four in number, they have been more correctly assigned to the order Neuroptera. Kirby regards them as forming, together with the ants, a link between the orders Neuroptera and Hymenoptera, being allied to the latter by their social instincts.

2. Scarcely less remarkable than the bee in their social organisation, they differ from that insect inasmuch as while the labours of the latter are attended with no evil to mankind, but are, on the contrary, productive of an eminently useful and agreeable article of food, the Termites, so far as naturalists have yet discovered, are productive of nothing but extensive and unmitigated mischief.

3. These insects live in societies, each of which consists of countless numbers of individuals, the large majority of which are apterous, or wingless. Two individuals only in each society, a male and a female, or according to some, a king and a queen, are winged, and these alone in the entire society are specimens of the perfect insect. The general form of their bodies is shown in

fig. 1 and fig. 2; the former representing the species called the *Termes embia*, with its wings expanded, and the latter the *Termes fatalis* or *bellicosus*, with its wings folded.

4. With the exception of two or three small species, such as the *Termes lucifugus*, described by Latreille and Rossi; the *Termes flavicollis*, described by Fabricius; and the *Termes flavipes*, described by Kollar, these insects are confined chiefly to the tropics.

5. Each society consists of five orders of individuals—

I. The queen or female.
II. The king or male.
III. The workers.
IV. The nymphs.
V. The neuters or soldiers.

The *Termes bellicosus* or *fatalis*, which is represented in fig. 2, with wings folded, is shown in fig. 3 with wings expanded.

The king or male, which never changes its form after losing its wings, is represented in fig. 4.

6. The worker is represented in its natural size in fig. 5, and the soldier in fig. 6.

A magnified view of the worker is given in fig. 7, and a similar magnified view of the forceps of the soldier in fig. 8.

7. The king and queen are privileged individuals, surrounded with all the respect and consideration, and receiving all the attendance and honours, due to sovereigns. Exempted from all participation in the common industry of the society, they are wholly devoted to increase and multiplication, the queen being endowed with the most unbounded fertility. Though upon first passing from the pupa state they have four wings, they lose these appendages almost immediately, and during the period of their sovereignty they are wingless. They are distinguished from the inferior members of the society by the possession of organs of vision, in the form of large and prominent eyes, their subjects being all of them blind.

8. The workers are by far the most numerous members of the society, being about a hundred times greater in number than the soldiers. Their bodies also, fig. 5, are less than those of the soldiers, the latter being less than those of the sovereigns. The entire industrial business of the society is performed by the workers. They erect the common habitation, and keep it in repair. They forage and collect provisions for the society. They attend upon the sovereigns, and carry away the eggs of the queen, as fast as she deposits them, to chambers which they previously prepare for them. They maintain these chambers in order, and when the eggs are hatched, they perform the part of nurses to the young,

feeding and tending them until they have attained sufficient growth to provide for themselves.

9. The soldiers, of whom, as already observed, there is not more than one to every hundred workers, are distinguished by their long and large heads, armed with long pointed mandibles. Their duty, as their title implies, is confined to the defence of the society and of their common habitation, when attacked by enemies.

10. The nymphs differ so little from the workers, that they would be confounded with them, but that they have the rudiments of wings, or, more strictly speaking, wings already formed, folded up in wing cases. These escaped the notice of the earliest observers, having been distinguished by Latreille.

11. Naturalists are not agreed as to the physiological character of these three classes of the society. Some consider the workers as the larvæ which, at a certain advanced period of their growth, are metamorphosed into the nymphs, which themselves finally pass into the state of the perfect winged insect.

According to Kirby, the soldiers correspond to the neuters in other societies of insects. As he observes, however, they differ from the neuters of the societies of Hymenoptera, which are a sort of sterile females. He conjectures that the soldiers may be the larvæ which are finally transformed into the perfect male insect. Great differences of opinion, however, prevail on this subject among entomologists.

For our present purpose, these doubtful questions, whatever interest they may have for naturalists, are altogether unimportant. What we desire at present to direct attention to, is the curious manners and habits of these insects, which have been ascertained by many eminent naturalists, and have been described with great minuteness by Smeathman in the seventy-first volume of the Philosophical Transactions, from whose memoir we shall here borrow largely.

According to Smeathman, the following is the manner in which the establishment of each colony takes place.

12. The pupæ or nymphs, which compose, as has been stated, part of a society, are transformed into the perfect insect, their wings being fully developed and liberated from the wing cases soon after the first tornado, which takes place at the close of the dry season, and harbingers the periodical rains. The insects, thus perfected, issue forth from their habitation in the evening, in numbers literally countless, swarming after the manner of bees. Borne upon their ample wings, and transported by the wind, they fill the air, entering houses, extinguishing lights, and being sometimes driven on board ships which happen to be near the shore. The next morning they are seen covering the surface of the earth

and waters, deprived of the wings which enabled them, for a moment, to escape their numerous enemies. They are now seen as large maggots, and, from being the most active, industrious, and sagacious of creatures, are become utterly helpless and cowardly, and fall a prey to innumerable enemies, to the smallest of which they do not attempt to offer the least resistance. Various insects, and especially ants, lie in wait for them; beasts, birds, and reptiles, and even man himself, all feed upon them, so that not one pair in many millions make their escape in safety, and fulfil the first law of nature by becoming the parents of a new community. At this time they may be seen running upon the ground, the male pursuing the female, and sometimes two pursuing one, and contending with the greatest eagerness for the prize, their passion rendering them regardless of the many dangers with which they are surrounded.

13. Mr. König, in an essay upon these insects, read before the society of naturalists at Berlin, says that, in some parts of the East Indies, the queens are given alive to old men for strengthening the back, and that the natives have a method of catching the winged insects, which he calls females, before the time of emigration. They make two holes in the nest; the one to windward and the other to leeward. At the leeward opening, they place the mouth of a pot, previously rubbed with an aromatic herb, called Bergera, which is more valued there than the laurel in Europe. On the windward side they light a fire of stinking materials, the smoke of which not only drives these insects into the pots, but frequently the hooded snakes also, on which account they are obliged to be cautious in removing them. By this method they catch great quantities, of which they make with flour a variety of pastry, which they can afford to sell very cheap to the poorer ranks of people. Mr. König adds, that in seasons when this kind of food is very plentiful, the too great use of it brings on an epidemic cholic and dysentery, which kills in two or three hours.

Mr. Smeathman says, that he did not find the Africans so ingenious in procuring or dressing them. They are content with a very small part of those which, at the time of swarming, or rather of emigration, fall into the neighbouring waters, which they skim off with calabashes, bringing large kettles full of them to their habitations, and parch them in iron pots over a gentle fire, stirring them about as is usually done in roasting coffee. In that state, without sauce or any other addition, they serve them as delicious food, and put them by handfuls into their mouths, as we do comfits. Smeathman ate them dressed in this way several times, and thought them delicate, nourishing, and wholesome. They are something sweeter, but not so fat or cloying, as the

caterpillar or maggot of the palm-tree snout beetle, which is served up at all the luxurious tables of West Indian epicures, particularly of the French, as the greatest dainty of the Western World.

14. Troops of workers, apparently deprived of their king and queen, which are constantly prowling about, occasionally encounter one of these pairs, to which they offer their homage, and seem to elect them as the sovereigns of their community, or the parents of the colony which they are about to establish. All the individuals of such a swarm, who are not so fortunate as to become the objects of such an election, eventually perish under the attacks of the enemies above mentioned, and probably never survive the day which follows the evening of their swarming.

15. So soon as this election has been made, the workers begin to enclose their new rulers in a small chamber of clay, suited to their size, the entrances to which are only large enough to admit themselves and the soldiers, but much too small for the royal pair to pass through, so that their state of royalty is a state of confinement, and so continues during the remainder of their lives.

16. The impregnation of the female is supposed to take place after this confinement, and she soon begins to furnish the infant colony with new inhabitants. The care of feeding her and her male companion devolves upon the workers, who supply them both with every thing that they want. As she increases in dimensions, they keep enlarging the cell in which she is detained. When the business of oviposition commences, they take the eggs from the female, and deposit them in the nurseries. Her abdomen now begins gradually to extend, till, in process of time, it is enlarged to 1500 or 2000 times the size of the rest of her body, and her bulk equals that of 20000 or 30000 workers.

17. A drawing of the pregnant queen in her natural size is given in fig. 9.

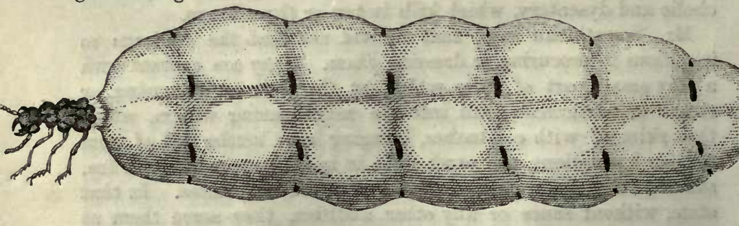


Fig. 9.—The Pregnant Queen.

18. The abdomen, often more than three inches in length, is now a vast matrix of eggs, which make long circumvolutions through numberless slender serpentine vessels: it is also remark-

able for its peristaltic motion (in this resembling the female ant), which, like the undulations of water, produces a perpetual and successive rise and fall over its whole surface, and occasions a constant extrusion of the eggs, amounting sometimes in old females to sixty in a minute, or eighty thousand and upwards in twenty-four hours. As these females live two years in their perfect state, how astonishing must be the number produced in that time!

19. This incessant extrusion of eggs must call for the attention of a large number of the workers in the royal chamber (and indeed it is always full of them), to take them as they come forth and carry them to the nurseries; in which, when hatched, they are provided with food, and receive every necessary attention until they are able to shift for themselves. One remarkable circumstance attends these nurseries. They are always covered with a kind of mould, amongst which arise numerous globules about the size of a small pin's head. This probably is a species of Mucor; and by Mr. König, who found them also in nests of an East India species of Termes, is conjectured to be the food of the larvæ.

20. The royal cell has in it a kind of body-guard to the royal pair that inhabit it; and the surrounding apartments always contain many, both labourers and soldiers in waiting, that they may successively attend upon and defend the common father and mother on whose safety depend the happiness and even existence of the whole community, and whom these faithful subjects never abandon, even in their last distress.

21. The habitations of the Termites, which are generally of considerable magnitude, vary in form, arrangement, and position, according to the species. Those of the *Termes bellicosus*, described above, have generally a sugar-loaf or hay-cock form, and are from ten to twelve feet high. In the parts of Africa where the insect prevails, these structures are so numerous that it is scarcely possible to find a spot from which they are not visible in all directions within fifty or sixty yards. In the neighbourhood of Senegal, according to Adanson, their number and magnitude is so great that they cannot be distinguished from the native villages.

22. When first erected, the external surfaces of these conical-shaped habitations consist of naked clay, but in these fertile climates the seeds of herbage transported by the wind are speedily deposited upon them, which germinating soon clothe them with the same vegetation as that which covers the surrounding soil, and when in the dry and warm season this vegetable covering is scorched, they assume the appearance of large hay-cocks.

23. These vast mounds are formed of earth which has been excavated by the workers from extensive tunnels which have

been carried beneath the ground surrounding their base, and which supply covered ways by which the workers are enabled to go forth in quest of provisions. The interior of the mounds themselves are of most curious and complicated structure, consisting of a variety of chambers and corridors, formed with the most consummate art, and adapted in shape and size to the respective purposes to which they are assigned in the general economy of the colony.

24. In the superior part of the mound, a dome is constructed, surmounting the habitations of the animals so as effectively to shelter them from the vicissitudes of weather. This may be seen in the vertical section of one of these mounds, shown in fig. 10. The exterior covering of this dome is much stronger than the internal structure beneath it, which constitutes the habitation of the colony, and which is divided with surprising regularity and contrivance into a vast number of chambers, one of which is appropriated to the sovereigns, and the others distributed among the soldiers, the workers, as nurseries, and as store-rooms. The process by which these conical structures are raised is thus described.

25. The habitation makes its first appearance as one or two small sugar-loaf-shaped mounds about a foot in height. While these are gradually increasing in height and magnitude, others begin to appear near them, which likewise increase in number; and by the enlargement of their basis, they at length coalesce at the lower parts. The middle mounds are always the highest, and the largest, and by gradually filling up the intermediate space by the enlargement of the bases of the several mounds, a single mound, with various sugar-loaf-shaped masses of less magnitudes growing out of it, is produced, as shown in fig. 10.

a a a. Turrets by which their hills are raised and enlarged.

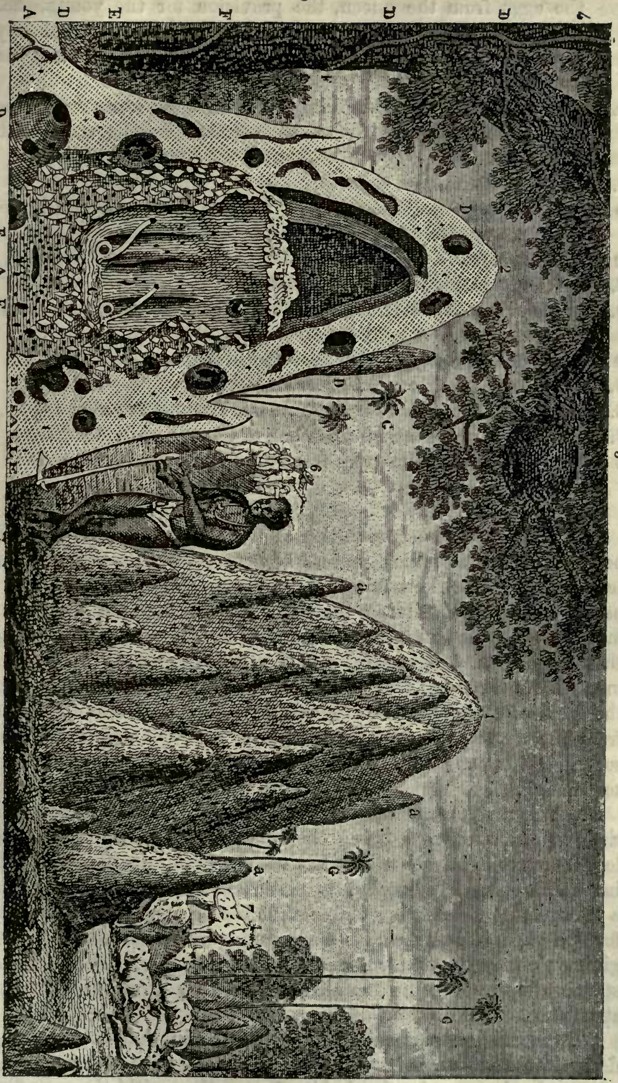
2. A section of 1, as it would appear on being cut down through the middle, from the top to the bottom, a foot lower than the surface of the ground.

A A. An horizontal line from A on the left, and a perpendicular line from A at the bottom will intersect each other at the royal chamber.

The darker shades near it are the empty apartments and passages, which, it seems, are left so for the attendants on the king and queen, who, when old, may require near one hundred thousand to wait on them every day.

The parts which are least shaded and dotted, are the nurseries, surrounded, like the royal chamber, by empty passages on all sides, for the more easy access to them with

Fig. 10.



View of the Habitations of the White Ants, reproduced from the original drawing of Smeathman, engraved in the "Phil. Trans.," vol. lxxi.

the eggs from the queen, the provision for the young, &c. N.B. The magazines of provisions are situated without any seeming order, among the vacant passages which surround the nurseries.

B. The top of the interior building, which often seems, from the arches carried upward, to be adorned on the sides with pinnacles.

C. The floor of the area or nave.

D D D. The large galleries which ascend from under all the buildings spirally to the top.

E E. The bridge.

3. The first appearance of a hill-nest by two turrets.

4. A tree with the nest of the *Termites arborum*, with their covered way.

F F F F. Covered ways of the *Termites arborum.*

5. The nest of the *Termites arborum.*

6. A nest of the *Termites bellicosi*, with Europeans on it.

7. A bull standing sentinel upon one of these nests.

G G G. The African palm-trees from the nuts of which is made the *Oleum palmæ.*

26. When by the accumulation of these turrets the dome has been completed, in which process the turrets supply the place of scaffolding, the workers excavate the interior of them, and make use of the clay in building the partitions and walls of the apartments constructed in the base of the mound which constitutes their proper habitation, and also for erecting fresh turrets surmounting the mound and increasing its height. In this manner the same clay, which, as has been already explained, was excavated from the underground ways issuing around the mound, is used several times over, just as are the posts and boards of a mason's scaffolding.

27. When these mounds have attained a little more than half their height, their tops being then flat, the bulls which are the leaders of the herds of wild cattle which prevail in the surrounding country, are accustomed to mount upon them so as to obtain a view of the surrounding plain: thus placed they act as sentinels for the general herd which feeds and ruminates around them, giving them notice of the approach of any danger. This circumstance supplies an incidental proof of the strength of these structures.

28. Smeathman states that when he was in that country, and desired to obtain a view of the sea to ascertain the approach of vessels, he was in the habit of mounting with three or four of his assistants upon the summits of these conical mounds,

the elevation of which was sufficient to enable him to obtain a satisfactory view.

29. The superior shell or dome by which the mound is surmounted is not only of use to protect the interior buildings from external violence and from the tropical rains, but, from its non-conducting quality, to preserve that uniform temperature within, which is necessary for hatching the eggs and cherishing the young.

30. The royal chamber appropriated to the sovereigns engrosses much of the attention and skill of their industrious subjects. It is generally placed about the centre of the base of the mound, at the level of the surrounding ground, and has the shape of half an egg divided by a plane at right angles to its axis passing a little below its centre. Thus the shape of this chamber is that which architects call a surmounted dome. Its magnitude is proportioned to that of the king and queen to whom it is appropriated. In the infant state of the colony, before the queen is advanced in pregnancy, the diameter of this room does not exceed an inch, but as the royal lady increases in the manner already described, the workers continually enlarge the room, until at length it attains a diameter of eight or nine inches. Its floor is perfectly level, and formed of clay about an inch thick. The roof is formed of a solid well-turned oval arch increasing in thickness from a quarter of an inch at the sides where it rests upon the floor.

31. The doors are cut in the wall, and made of a magnitude suitable to the entrance and exit of the soldiers and workers who attend on the royal pair, but much too small for the passage of the royal personages themselves.

32. This large chamber is surrounded by numerous others of less dimensions, and various shapes, all of which have arched roofs, some circular, and some elliptical. These chambers communicate with each other by doors and corridors. Those which are immediately contiguous to the royal chamber are appropriated to the soldiers, who are in immediate attendance on the sovereign, and to the workers, whose duty it is to supply and attend the royal table, and to carry away the eggs as fast as they are laid by the queen.

33. Around these antechambers is another suite of apartments, consisting of store-rooms for provisions, chambers for the reception of the eggs, and nurseries for the young. The store-rooms are constructed like other parts of the habitation, with walls and partitions of clay, and are always amply supplied with provisions, which, to the naked eye, seem to consist of the raspings of wood and plants, which the workers destroy. Upon submitting them to the microscope, however, they are found to consist prin-

cipally of vegetable gums and inspissated juices. These are thrown together in masses of different appearance, some resembling the sugar on preserved fruits, some transparent, and others opaque, as is commonly seen in all parcels of gum.

The nurseries, on the other hand, are constructed in a manner totally different from the other rooms.

34. The walls and partitions of these consist entirely of wooden materials, cemented together with gum. These nurseries, in which the eggs are hatched, and the young secured, are small irregularly shaped rooms, none of which exceed half an inch in width.

35. When the nest is in the infant state, the nurseries are close to the royal chamber; but as in process of time the queen enlarges, it is necessary to enlarge the chamber for her accommodation; and as she then lays a great number of eggs, and requires a greater number of attendants, so it is necessary also to enlarge and increase the number of the antechambers; for which purpose the small nurseries first built] are taken to pieces, rebuilt a little further off a size larger, and their number increased.

36. Thus they continually enlarge their apartments, pull down, repair, or rebuild, according to their wants, with a degree of sagacity, regularity, and foresight, not observed among any other kind of animals or insects.

37. There is one remarkable circumstance attending the nurseries which ought not to be omitted. They are always found slightly overgrown with mould, and plentifully sprinkled with white globules, about the size of the head of a small pin. These may be at first mistaken for eggs; but submitting them to the microscope, they appear to be a species of mushroom, similar to the common mushroom, of the sort usually pickled. They appear, when whole, white like snow a little thawed and afterwards frozen; and, when bruised, seem to be composed of an infinite number of pellucid particles, having a nearly oval form, and difficult to be separated. The mouldiness seems to be composed of the same kind of substance. The nurseries are enclosed in chambers of clay, like the store-rooms, but much larger. In the early state of the nest, they are not bigger than a hazel-nut, but in large hills are much more spacious.

38. These magazines and nurseries, separated by small empty chambers and galleries, which run round them, or communicate from one to the other, are continued on all sides to the outer wall of the building, and reach up within it to two-thirds or three-fourths of its height. They do not, however, fill up the whole of the lower part of the hill, but are confined to the sides, leaving an open area in the middle, under the dome, very much resem-

bling the nave of an old cathedral, having its roof supported by three or four very large Gothic arches, of which those in the middle of the area are sometimes two and three feet high; but as they recede on each side, rapidly diminish, like the arches of aisles in perspective. A flattish roof, without perforation, in order to keep out the wet, if the dome should chance to be injured, covers the top of the assemblage of chambers, nurseries, &c.; and the area, which is above the royal chambers, has a flattish floor, also water-proof, and so contrived as to let any rain that may chance to get in, run off into the subterraneous passages which run from the basement of the lower apartments through the hill in various directions; and one of astonishing magnitude, often having a bore greater than that of a large piece of ordnance. Smeathman measured the diameter of one of these passages, which was perfectly cylindrical, and found it to be thirteen inches.

39. These subterraneous passages, or galleries, are lined very thick with the same kind of clay of which the hill is composed, and ascend the inside of the outer shell in a spiral manner, and winding round the whole building, up to the top, intersect each other at different heights, opening either immediately into the dome in various places, and into the interior building, the new turrets, &c., or communicating thereto by other galleries of different bores or diameter, either circular or oval.

From every part of these large galleries are various small tunnels or galleries, leading to different parts of the building. Under ground there are many which lead downward, by sloping descents, three or four feet perpendicular, among the gravel, from whence the workers cull the finer parts, which, being worked up in their mouths to the consistence of mortar, become that solid clay of which their hills and all their buildings, except their nurseries, are composed.

40. Other galleries again ascend, and lead out horizontally on every side, and are carried under ground, near to the surface, to a vast distance: for if you destroy all the nests within one hundred yards of your house, the inhabitants of those which are left unmolested farther off will, nevertheless, carry on their subterraneous galleries, and invade the goods and merchandises contained in it by sap and mine, and do great mischief, if you are not very circumspect.

41. But to return to the cities from whence these extraordinary expeditions and operations originate, it seems there is a degree of necessity for the galleries under the hills being thus large, being the great thoroughfares for all the labourers and soldiers going forth or returning upon any business whatever, whether

fetching clay, wood, water, or provisions; and they are certainly well calculated for the purposes to which they are applied, by the spiral slope which is given them; for if they were perpendicular, the labourers would not be able to carry on their building with so much facility, since they cannot ascend a perpendicular without great difficulty, and the soldiers can scarcely do it at all. It is on this account that sometimes a road, like a ledge, is made on the perpendicular side of part of the building within their hill, which is flat on the upper surface, and half an inch wide, and ascends gradually like a staircase, or like those roads which are cut on the sides of hills and mountains, that would otherwise be inaccessible; by which, and similar contrivances, they travel with great facility to every interior part.

42. This too is probably the cause of their building a kind of bridge of one vast arch, which answers the purpose of a flight of stairs from the floor of the area to some opening on the side of one of the columns which support the great arches. Such bridges shorten the distance considerably to those labourers who have the eggs to carry from the royal chamber to some of the upper nurseries, which in some hills would be four or five feet in the straightest line, and much more if carried through all the winding passages which lead through the inner chambers and apartments.

Smeathman found one of these bridges half an inch broad, a quarter of an inch thick, and ten inches long, making the side of an elliptic arch of proportional size; so that it is wonderful it did not fall over or break by its own weight before they got it joined to the side of the column above. It was strengthened by a small arch at the bottom, and had a hollow or groove all the length of the upper surface, either made purposely for the inhabitants to travel over with more safety, or else, which is not improbable, worn so by frequent treading.

43. "Consider," observes Kirby, "what incredible labour and diligence, accompanied by the most unremitting activity and the most unwearied celerity of movement, must be necessary to enable these creatures to accomplish, their size considered, these truly gigantic works. That such diminutive insects, for they are scarcely the fourth of an inch in length, however numerous, should, in the space of three or four years, be able to erect a building twelve feet high, and of a proportionable bulk, covered by a vast dome, adorned without by numerous pinnacles and turrets, and sheltering under its ample arch myriads of vaulted apartments of various dimensions, and constructed of different materials—that they should moreover excavate, in different directions, and at different depths, innumerable subterranean roads or tunnels,

some twelve or thirteen inches in diameter, or throw an arch of stone over other roads leading from the metropolis into the adjoining country to the distance of several hundred feet—that they should project and finish the, for them, vast interior staircases or bridges lately described—and, finally, that the millions necessary to execute such Herculean labours, perpetually passing to and fro, should never interrupt or interfere with each other, is a miracle of nature, or rather of the Author of nature, far exceeding the most boasted works and structures of man: for, did these creatures equal him in size, retaining their usual instincts and activity, their buildings would soar to the astonishing height of more than half a mile, and their tunnels would expand to a magnificent cylinder of more than three hundred feet in diameter; before which the pyramids of Egypt and the aqueducts of Rome would lose all their celebrity, and dwindle into nothings.

"The most elevated of the pyramids of Egypt is not more than 600 feet high, which, setting the average height of man at only five feet, is not more than 120 times the height of the workmen employed. Whereas the nests of the Termites being at least twelve feet high, and the insects themselves not exceeding a quarter of an inch in stature, their edifice is upwards of 500 times the height of the builders; which, supposing them of human dimensions, would be more than half a mile. The shaft of the Roman aqueducts was lofty enough to permit a man on horseback to travel in them." *

44. The bodies of the Termites are generally soft and covered with a thin and delicate skin, and being blind, they are no match on the open ground for the ants who are endowed with vision, and whose bodies are invested in a strong horny shell. Whenever the Termites are accidentally dislodged from their subterraneous roads or dwellings, the various species of ants instantly seize them and drag them away to their nests as food for their young.

45. The Termites are therefore very solicitous about preserving their tunnels and vaulted roads in good repair. If some of them be accidentally demolished for a few inches in length, it is wonderful how speedily they rebuild it. At first, in their hurry, they advance into the open part for an inch or two, but stop so suddenly that it is very apparent that they are surprised, for although some run straight on until they get under the arch beyond the damaged part, most of them run as fast back, and very few of them will venture through that part of the track which is left uncovered. In a few minutes, however, they will be seen rebuilding the arch, and even if three or four yards in length have been destroyed, they will reconstruct it in a single day. If this be again destroyed,

* Kirby, vol. i. p. 434.

they will be seen as numerous as ever passing both ways along it, and they will again in like manner reconstruct it. But if the same part be destroyed several times successively, they will give up the point and build a new covered way in another direction. Nevertheless, if the old one should lead to some favourite source of plunder, they will, after a few days' interval, still reconstruct it, apparently in the hope that the cause of destruction will not again occur, nor will they in that case wholly abandon the undertaking unless their habitation itself be destroyed.

Fig. 5.—Worker.

Fig. 6.—Soldier.

Fig. 7.—Worker, magnified.

Fig. 8.—Forceps of Soldier, magnified.

THE WHITE ANTS,

THEIR MANNERS AND HABITS.

CHAPTER II.

46. Turrets built by the Termes mordax and the Termes atrox.—47. Description of their structure.—48. Their king, queen, worker, and soldier.—49. Internal structure of their habitation.—50. Nests of the Termes arborum.—51. Process of their construction.—52. Hill nests on the Savannahs.—53. The Termes lucifugus—the organisation of their societies.—54. Habits of the workers and soldiers—the materials they use for building.—55. Their construction of tunnels.—56. Nests of the Termes arborum in the roofs of houses.—57. Destructive habits of the Termes bellicosus in excavating all species of wood-work—entire houses destroyed by them.—58. Curious process by which they fill with mortar the excavations which they make—destruction of Mr. Smeathman's microscope.—59. Destruction of shelves and wainscoting.—60. Their artful process to escape observation.—61. Anecdotes of them by Kœmpfer and Humboldt.—62. Destruction of the Governor's house at Calcutta—destruction by them of a British ship of the line.—63. Their manner of attacking timber in the open air—their wonderful power of destroying fallen timber.—64. The extraordinary behaviour of the soldiers when a nest is attacked.

65. Their rage and fury against those who attack them.—66. Their industry and promptitude in repairing the damage of their habitation. —67. The vigilance of the soldiers during the process of repair.— 68. Effects of a second attack on their habitation, conduct of the soldiers.—69. Difficulty of investigating the structure of their habitations—obstinate opposition of the soldiers—discovery of the royal chamber—fidelity of the subjects to the sovereign—curious experiment of Mr. Smeathman.—70. Curious example of the repair of a partially destroyed nest.—71. The marching Termites—curious observation of their proceedings by Smeathman—remarkable conduct of the soldiers on the occasion.

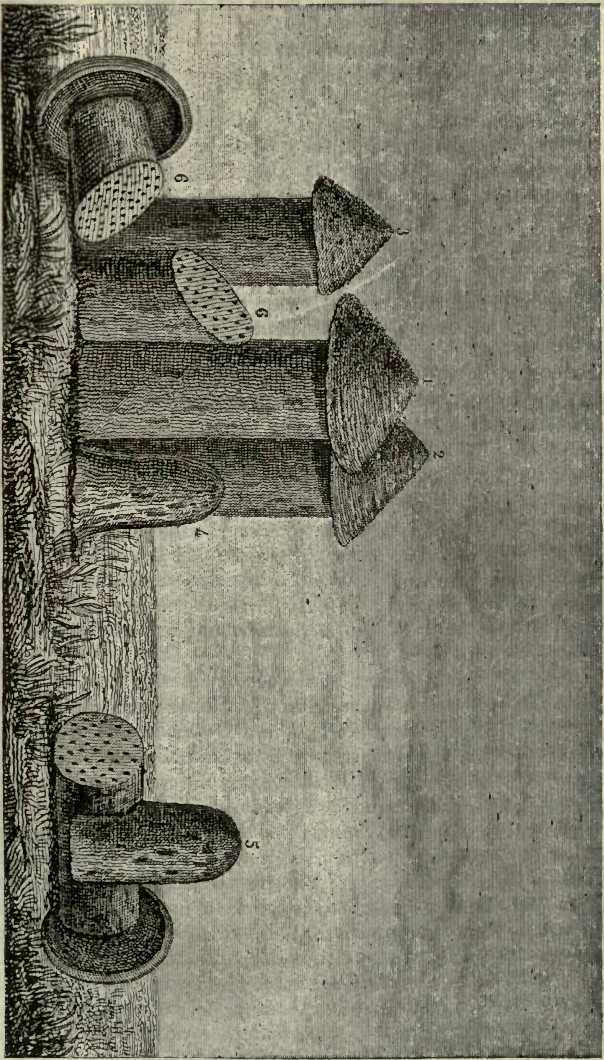
46. A smaller species of Termites erect habitations, which, if they are of less dimensions, are not less curious in their structure. These buildings are upright cylinders, composed of a well-tempered black earth or clay, about three quarters of a yard high, and covered with a roof of the same material in the shape of a cone, whose base extends over and hangs down three or four inches wider than the perpendicular sides of the cylinder, so that most of them resemble in shape a round windmill, or still more closely the round towers which are so frequently seen in Ireland, and which have attracted so much attention on the part of antiquaries. Some of these roofs have so little elevation in the centre, that they have a close resemblance to certain species of mushroom.

After one of these turrets is finished, it is not altered or enlarged; but when no longer capable of containing the community, the foundation of another is laid within a few inches of it. Sometimes, though but rarely, the second is begun before the first is finished, and a third before they have completed the second: thus they will run up five or six of these turrets at the foot of a tree in the thick woods, and make a most singular group of buildings, as shown in fig. 11.

1 Nest of the *Termes mordax.*
2 Nest of the *Termes atrox.*
3 A turret with the roof begun.
4 A turret raised only about half its height.
5 A turret built upon one which has been thrown down.
6 6 A turret broken in two.

47. The turrets are so strongly built, that in case of violence they will much sooner overset from the foundations, and tear up the ground and solid earth, than break in the middle; and in that case the insects will frequently begin another turret and build it, as it were, through that which has fallen; for they will connect the cylinder below with the ground, and run up a new turret from its upper side, so that it will seem to rest upon the horizontal cylinder only.

Fig. 11.



The Turret Nests of the Termes Mordax and Termes Atrox.

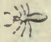
48. In fig. 12 is represented the king or queen of the *Termes mordax*, in fig. 13 the worker, and in fig. 14 the soldier.

TERMES MORDAX.

Fig. 12.

King or Queen.

Fig. 13.



Worker.

Fig. 14.

Soldier.

The building is divided into innumerable cells of irregular shapes; sometimes they are quadrangular or cubic, and sometimes pentagonal; but often the angles are so ill defined, that each half of a cell will be shaped like the inside of that shell which is called the sea-ear.

49. Each cell has two or more entrances, but as there are no tunnels or galleries, no variety of apartments, no well-turned arches, wooden nurseries, &c., &c., as in the habitations already described, they are not calculated to excite the same degree of wonder, however admirable they may be considered without reference to other structures.

There are two sizes of these turret nests, built by two different species of Termites. The larger species, the *Termes atrox*, in its perfect state, measures one inch and three-tenths from the extremities of the wings on the one side to the extremities on the other. The lesser, *Termes mordax*, measures only eight-tenths of an inch from tip to tip.

50. The next kind of nests, built by another species of this genus, the *Termes arborum*, have very little resemblance to the former in shape or substance. These are generally spherical or oval, built in trees: sometimes they are established between, and sometimes surrounding, the branches, at the height of seventy or eighty feet; and are occasionally as large as a great sugar-cask.

51. They are composed of small particles of wood and the various gums and juices of trees, combined with, perhaps, those secreted by the animals themselves, worked by those little industrious creatures into a paste, and so moulded into innumerable little cells of different and irregular forms. These nests, with the immense quantity of inhabitants, young and old, with which they are at all times crowded, are used as food for young fowls, and especially for the rearing of Turkeys. These nests are very compact, and so strongly fixed to the boughs, that there is no detaching them but by cutting them in pieces, or sawing off the branch. They will even sustain the force of a tornado as long as the tree to

which they are attached. This species has the external habit, size, and almost the colour, of the *Termes atrox.*

52. There are some nests that resemble the hill-nests first described, built in those sandy plains called Savannahs. They are composed of black mud, raised from a few inches below the white sand, and are built in the form of an imperfect or bell-shaped cone, having their tops rounded. These are generally about four or five feet high. They seem to be inhabited by insects nearly as large as the *Termes bellicosus*, and differing very little from that species, except in colour, which is brighter.

53. The societies of *Termes lucifugus*, discovered by Latreille at Bourdeaux, are very numerous; but instead of making artificial nests, they make their lodgments in the trunks of pines and oaks, where the branches diverge from the tree. They eat the wood the nearest the bark without attacking the interior, and bore a vast number of holes and irregular galleries. That part of the wood appears moist, and is covered with little gelatinous particles, not unlike gum-arabic. These insects seem to be furnished with an acid of a very penetrating odour, which, perhaps, is useful to them in softening the wood. The soldiers in those societies are as about one to twenty-five of the labourers.

The anonymous author of the Observations on the Termites of Ceylon, seems to have discovered a sentry-box in his nests. "I found," says he, "in a very small cell in the middle of the solid mass, (a cell about half an inch in height, and very narrow,) a larva with an enormous head. Two of these individuals were in the same cell; one of the two seemed placed as sentinel at the entrance of the cell. I amused myself by forcing the door two or three times; the sentinel immediately appeared, and only retreated when the door was on the point to be stopped up, which was done in three minutes by the labourers."

54. Having thus given some idea of their habitations, we shall now direct our observations to the insects themselves, their manner of building, fighting, and marching, and to a more particular account of the vast mischief they cause to mankind.

It is a common character of the different species which have been noticed, that the workers and the soldiers never expose themselves in the open air, but invariably travel either under ground, or along the holes which they bore in trees and other substances. When in certain exceptional cases in quest of plunder they are compelled to move above ground, they make a vault with a coping of earth, or a tube, formed of that material with which they build their nests, along which they travel completely protected. The *Termes bellicosus* uses for this purpose the red, and the turret-builders black clay; whilst the *Termes*

arborum employs for the purpose the ligneous substances of which their nests are composed.

55. With these materials they completely line most of the roads leading from their nests into the various parts of the country, and travel out and home with the utmost security in all kinds of weather. If they meet a rock or any other obstruction, they will make their way upon the surface, and for that purpose erect a covered way or arch, still of the same materials, continuing it with many windings and ramifications through large grooves, having, where it is possible, subterranean pipes running parallel with them, into which they sink, and save themselves, if their galleries above ground are destroyed by any violence, or the tread of men or animals alarms them. When any one chances by accident to enter any solitary grove, where the ground is pretty well covered with their arched galleries, they give the alarm by loud hissings, which he hears distinctly at every step he makes; soon after which he may examine their galleries in vain for the insects, which escape through little holes, just large enough for them, into their subterraneous roads. These galleries are large enough for them to pass and repass, so as to prevent any stoppages, and shelter them equally from light and air, as well as from their enemies, of which the ants, being the most numerous, are the most formidable.

56. The *Termites arborum*, those which build in trees, frequently establish their nests within the roofs and other parts of houses, to which they do considerable damage if not extirpated.

57. The larger species are, however, not only much more destructive, but more difficult to be guarded against, since they make their approaches chiefly under ground, descending below the foundations of houses and stores at several feet from the surface, and rising again either in the floors, or entering at the bottoms of the posts, of which the sides of the buildings are composed, bore quite through them, following the course of the fibres to the top, or making lateral perforations and cavities here and there as they proceed.

While some are employed in gutting the posts, others ascend from them, entering a rafter or some other part of the roof. If they once find the thatch, which seems to be a favourite food, they soon bring up wet clay, and build their pipes or galleries through the roof in various directions, as long as it will support them, sometimes eating the palm-tree leaves and branches of which it is composed, and perhaps (for variety seems very pleasing to them) the rattan or other running plant which is used as a cord to tie the various parts of the roof together, and to the posts which support it; thus, with the assistance of the rats, who,

during the rainy season, are apt to shelter themselves there, and to burrow through it, they very soon ruin the house by weakening the fastenings and exposing it to the wet. In the meantime, the posts will be perforated in every direction, as full of holes as that timber in the bottom of ships which has been bored by the worms; the fibrous and knotty parts, which are the hardest, being left to the last.

58. They sometimes, in carrying on this business, find that the post has some weight to support, and then, if it is a convenient track to the roof, or is itself a kind of wood agreeable to them, they bring their mortar, and fill all or most of the cavities, leaving the necessary roads through it, and as fast as they take away the wood, replace the vacancy with that material; which being worked together by them closer and more compactly than human strength or art could ram it, when the house is pulled to pieces, in order to examine if any of the posts are fit to be used again, those of the softer kinds are often found reduced almost to a shell, and all, or a greater part, transformed from wood to clay, as solid and as hard as many kinds of freestone used for building in England.

It is much the same when the *Termites bellicosi* get into a chest or trunk containing clothes and other things; if the weight above is great, or they are afraid of ants and other enemies, and have time, they carry their pipes through, and replace a great part with clay, running their galleries in various directions. The tree-Termites, indeed, when they get within a box, often make a nest there, and being once in possession destroy it at their leisure. They did so in a pyramidal box which contained the compound microscope of Mr. Smeathman. It was of mahogany, and he deposited it in the warehouse of Governor Campbell of Tobago, while he made a tour of a few months in the Leeward Islands. On his return he found that the Termites had done much mischief in the warehouse, and, among other things, had taken possession of the microscope, and eaten everything about it except the glass or metal, including the board on which the pedestal is fixed, with the drawers under it, and the things enclosed. The cells were built all round the pedestal and the tube, and attached to it on every side. All the glasses were covered with the wooden substance of their nests, and retained a cloud of a gummy nature upon them which was not easily got off, and the lacquer or burnish with which the brasswork was covered was totally spoiled.

Another party had taken a liking to a cask of Madeira, and had bored so as to discharge almost a pipe of fine old wine. If the large species of Africa (the *Termites bellicosi*) had been so

long in the uninterrupted possession of such a warehouse, they would not have left twenty pounds weight of wood remaining of the whole building, and all that it contained.

59. These insects are not less expeditious in destroying the shelves, wainscotting, and other fixtures of a house, than the house itself. They are for ever piercing and boring in all directions, and sometimes go out of the broadside of one post into that of another joining to it; but they prefer, and always destroy the softer substances the first, and are particularly fond of pine and fir-boards, which they excavate and carry away with wonderful despatch and astonishing cunning; for, unless a shelf has something standing upon it, as a book, or anything else which may tempt them, they will not perforate the surface, but artfully preserve it quite whole, and eat away all the inside, except a few fibres which barely keep the two sides connected together, so that a piece of an inch board which appears solid to the eye will not weigh much more than two sheets of pasteboard of equal dimensions, after these animals have been a little while in possession of it.

60. In short the Termites are so insidious in their attacks, that we cannot be too much on our guard against them: they will sometimes begin and raise their works, especially in new houses, through the floor. If you destroy the work so begun, and make a fire upon the spot, the next night they will attempt to rise through another part; and, if they happen to emerge under a chest or trunk early in the night, will pierce the bottom, and destroy or spoil everything in it before morning. On these accounts care is taken by the inhabitants of the country to set all their chests and boxes upon stones or bricks, so as to leave the bottoms of such furniture some inches above the ground; which not only prevents these insects finding them out so readily, but preserves the bottoms from a corrosive damp which would strike from the earth through, and rot everything therein; a vast deal of vermin would also harbour under, such as cockroaches, centipedes, millepedes, scorpions, ants, and various other noisome insects.

61. Kœmpfer, speaking of the white ants of Japan, gives a remarkable instance of the rapidity with which these miners proceed. Upon rising one morning, he observed that one of their galleries, of the thickness of his little finger, had been formed across his table; and upon a further examination he found that they had bored a passage of that thickness up one foot of the table, formed a gallery across it, and then pierced down another foot into the floor; all this was done in the few hours that intervened between his retiring to rest and his rising. They make

their way also with the greatest ease into trunks and boxes, even though made of mahogany, and destroy papers and everything they contain, constructing their galleries and sometimes taking up their abode in them. Hence, as Humboldt informs us, throughout all the warmer parts of equinoctial America, where these and other destructive insects abound, it is infinitely rare to find papers which go fifty or sixty years back. In one night they will devour all the boots and shoes that are left in their way; cloth, linen, or books are equally to their taste; but they will not eat cotton. They entirely consumed a collection of insects made in India. In a word, scarcely anything but metal or stones comes amiss to them.

62. It is even asserted that the superb residence of the Governor-General at Calcutta, which cost the East India Company such immense sums, is now rapidly going to decay in consequence of the attacks of these insects. But not content with the dominions they have acquired, and the cities they have laid low on terra firma, encouraged by success, the white ants have also aimed at the sovereignty of the ocean, and once had the hardihood to attack even a British ship of the line; and in spite of the efforts of the commander and his valiant crew, having boarded they got possession of her, and handled her so roughly, that when brought into port, being no longer fit for service, she was obliged to be broken up.

The ship here alluded to was the Albion, which was in such a condition from the attack of these insects, that had it not been firmly lashed together, it was thought she would have foundered on her voyage home. The late Mr. Kittoe stated that the *droguers* or *draguers*, a kind of lighter employed in the West Indies in collecting the sugar, sometimes so swarm with ants of the common kind, that they have no other way of getting rid of these troublesome insects than by sinking the vessel in shallow water.

63. When the Termites attack trees and branches in the open air, they sometimes vary their manner of doing it. If a stake in a hedge has not taken root and vegetated, it becomes their business to destroy it. If it has a good sound bark round it, they will enter at the bottom, and eat all but the bark, which will remain, and exhibit the appearance of a solid stick (which some vagrant colony of ants or other insects often shelter in, till the winds disperse it); but if they cannot trust the bark, they cover the whole stick with their mortar, and it then looks as if it had been dipped into thick mud that had been dried on. Under this covering they work, leaving no more of the stick and bark than is barely sufficient to support it, and frequently not the smallest particle, so that upon a very small tap with your walking stick,

the whole stake, though apparently as thick as your arm, and five or six feet long, loses its form, and, disappearing like a shadow, falls in small fragments at your feet. They generally enter the body of a large tree which has fallen through age, or been thrown down by violence, on the side next the ground, and eat away at their leisure within the bark, without giving themselves the trouble either to cover it on the outside, or to replace the wood which they have removed from within, being somehow sensible that there is no necessity for it. "Such excavated trees," says Mr. Smeathman, "deceived me two or three times in running; for, attempting to step two or three feet high, I might as well have attempted to step upon a cloud, and have come down with such unexpected violence, that, besides shaking my teeth and bones almost to dislocation, I have been precipitated head foremost among the neighbouring trees and bushes." Sometimes, though seldom, the animals are known to attack living trees; but not before symptoms of mortification have appeared at the roots; since it is evident that these insects are intended in the order of nature to hasten the dissolution of such trees and vegetables as have arrived at their greatest maturity and perfection, and which would, by a tedious decay, serve only to encumber the face of the earth. This purpose they answer so effectually that nothing perishable escapes them, and it is almost impossible to leave anything penetrable upon the ground a long time in safety; for the odds are, put it where you will abroad, they will find it out before the following morning, and its destruction follows very soon of course. In consequence of this disposition, the woods never remain long encumbered with the fallen trunks of trees or their branches; and thus it is that the total destruction of deserted towns is so effectually completed, that in two or three years a thick wood fills the space; and, unless *iron-wood* posts have been made use of, not the least vestige of a house is to be discovered.

64. The first object of admiration, which strikes one upon opening their hills, is the behaviour of their soldiers. If you make a breach in a slight part of the building, and do it quickly, with a strong hoe or pick-axe, in the space of a few seconds a soldier will run out, and walk about the breach, as if to see whether the enemy is gone, or to examine what is the cause of the attack. He will sometimes go in again, as if to give the alarm; but most frequently, in a short time, is followed by two or three others, who run as fast as they can, straggling after one another, and are soon followed by a large body, who rush out as fast as the breach will permit them, and so they proceed, the number increasing, as long as any one continues battering their building. It is not easy to describe the rage and fury they show.

In their hurry they frequently miss their hold, and tumble down the sides of the hill, but recover themselves as quickly as possible; and being blind, bite everything they run against, and thus make a crackling noise, while some of them beat repeatedly with their forceps upon the building, and make a small vibrating noise, something shriller and quicker than the ticking of a watch. This noise can be distinguished at three or four feet distance, and continues for a minute at a time, with short intervals. While the attack proceeds, they are in the most violent bustle and agitation.

65. If they get hold of any one they will, in an instant, let out blood enough to weigh against their whole body; and if it is the leg they wound, you will see the stain upon the stocking extend an inch in width. They make their hooked jaws meet at the first stroke, and never quit their hold, but suffer themselves to be pulled away leg by leg, and piece after piece, without the least attempt to escape. On the other hand, keep out of their way, and give them no interruption, and they will, in less than half an hour, retire into the nest, as if they supposed the wonderful monster that damaged their castle to be gone beyond their reach.

66. Before they are all got in, you will see the labourers in motion, and hastening in various directions towards the breach; every one with a burthen of mortar in his mouth ready tempered. This they stick upon the breach as fast as they come up, and do it with so much dispatch and facility, that although there are thousands, and even millions of them, they never stop or embarrass one another; and you are most agreeably deceived when, after an apparent scene of hurry and confusion, a regular wall arises, gradually filling up the chasm. While they are thus employed, almost all the soldiers are retired quite out of sight, except here and there one, who saunters about among six hundred or a thousand of the labourers, but never touches the mortar either to lift or carry it; one, in particular, places himself close to the wall they are building.

67. This soldier will turn himself leisurely on all sides, and every now and then, at intervals of a minute or two, lift up his head, and with his forceps beat upon the building, and make the vibrating noise before mentioned; on which immediately a loud hiss, which appears to come from all the labourers, issues from within side the dome, and all the subterraneous caverns and passages: that it does come from the labourers is very evident, for you will see them all hasten at every such signal, redouble their pace, and work as fast again.

68. As the most interesting experiments become dull by repe-

tition or continuance, so the uniformity with which this business is carried on, though so very wonderful, at last satiates the mind. A renewal of the attack, however, instantly changes the scene, and gratifies our curiosity still more. At every stroke we hear a loud hiss; and on the first the labourers run into the many pipes and galleries with which the building is perforated, which they do so quickly that they seem to vanish, for in a few seconds all are gone, and the soldiers rush out as numerous and as vindictive as before. On finding no enemy they return again leisurely into the hill, and very soon after the labourers appear loaded as at first, as active and as sedulous, with soldiers here and there among them, who act just in the same manner, one or other of them giving the signal to hasten the business. Thus the pleasure of seeing them come out to fight or to work alternately may be obtained as often as curiosity excites or time permits; and it will certainly be found, that the one order never attempts to fight, or the other to work, let the emergency be ever so great.

69. We meet vast obstacles in examining the interior parts of these tumuli. In the first place the works, for instance, the apartments which surround the royal chamber and the nurseries, and indeed the whole internal fabric, are moist, and consequently the clay is very brittle; they have also so close a connection, that they can only be seen as it were by piecemeal; for having a kind of geometrical dependence or abutment against each other, the breaking of one arch pulls down two or three. To these obstacles must be added the obstinacy of the soldiers, who fight to the very last, disputing every inch of ground so well as often to drive away the negroes who are without shoes, and make white people bleed plentifully through their stockings. Neither can we let a building stand, so as to get a view of the interior parts without interruption, for while the soldiers are defending the outworks, the labourers keep barricading all the way against us, stopping up the different galleries and passages, which lead to the various apartments, particularly the royal chamber, all the entrances to which they fill up so artfully as not to let it be distinguishable, while it remains moist; and externally it has no other appearance than that of a shapeless lump of clay. It is, however, easily found from its situation with respect to the other parts of the building, and by the crowds of labourers and soldiers which surround it, who show their loyalty and fidelity by dying under its walls. The royal chamber, in a large nest, is capacious enough to hold many hundreds of the attendants, besides the royal pair, and you always find it as full of them as it can hold. These faithful subjects never abandon their charge, even in the last distress, for whenever Mr. Smeathman took out the royal

chamber from one of the hills, as he often did, and preserved it for some time in a large glass bowl, all the attendants continued running in one direction round the king and queen with the utmost solicitude, some of them stopping in every circuit at the head of the latter, as if to give her something; when they came to the extremity of the abdomen, they took the eggs from her, carrying them away, and piled them carefully together in some part of the chamber, or in the bowl under, or behind any pieces of broken clay, which lay most convenient for the purpose.

Some of these unhappy little creatures would ramble from the chamber as if to explore the cause of such a horrid ruin and catastrophe to their immense buildings, as it must appear to them; and after fruitless endeavours to get over the side of the bowl, return and mix with the crowd that continued running round their common parents to the last. Others, placing themselves along her side, would get hold of the queen's vast matrix with their jaws, and pull with all their strength, so as visibly to lift up the part which they fix at; but Mr. Smeathman who observed this, was unable to determine whether this pulling was with an intention to remove her body, or to stimulate her to move herself, or for any other purpose. After many ineffectual tugs, they would desist and join in the crowd running round, or assist some of those who are cutting off clay from the external parts of the chamber, or some of the fragments, and moistening it with the juices of their bodies, to begin to work a thin arched shell over the body of the queen, as if to exclude the air, or to hide her from the observation of some enemy. These, if not interrupted, before the next morning, completely cover her, leaving room enough within for great numbers to run about her.

The king, being very small in proportion to the queen, generally conceals himself under one side of her abdomen, except when he goes up to the queen's head, which he does now and then, but not so frequently as the rest.

70. If in your attack on the hill you stop short of the royal chamber, and cut down about half of the building, and leave open some thousands of galleries and chambers, they will all be shut up with thin sheets of clay before next morning. If even the whole is pulled down, and the different buildings are thrown in a confused heap of ruins, provided the king and queen are not destroyed or taken away, every interstice between the ruins, at which either cold or wet can possibly enter, will be so covered as to exclude both; and, if the animals are left undisturbed, in about a year they will raise the building to near its pristine size and grandeur.

71. The marching Termites are not less curious in their order

than those described before. This species seems much scarcer and larger than the *Termes bellicosus.* They are little known to the natives. Smeathman had an opportunity of observing them by mere accident; one day, having made an excursion with his gun up the river Camerankoes, on his return through the thick forest, while he was sauntering very silently in hopes of finding some sport, on a sudden he heard a loud hiss, which, on account of the many serpents in these countries, is a most alarming sound. The next step caused a repetition of the noise, which he soon recognised, and was rather surprised, seeing no covered ways or hills. The noise, however, led him a few paces from the path, where, to his great astonishment and pleasure, he saw an army of Termites coming out of a hole in the ground, which could not be above four or five inches wide. They came out in vast numbers, moving forward as fast seemingly as it was possible for them to march. In less than a yard from this place they divided into two streams or columns, composed chiefly of labourers, twelve or fifteen abreast, and crowded as close after one another as sheep in a drove, going straight forward, without deviating to the right or the left. Among these, here and there, one of the soldiers was to be seen, trudging along with them in the same manner, neither stopping nor turning; and as he carried his enormous large head with apparent difficulty, he appeared like a very large ox amongst a flock of sheep. While these were bustling along, a great many soldiers were to be seen spread about on both sides of the two lines of march, some a foot or two distant, standing still or sauntering about as if upon the look-out lest some enemy should suddenly come upon the workers. But the most extraordinary part of this march was the conduct of some others of the soldiers, who, having mounted the plants which grow thinly here and there in the thick shade, had placed themselves upon the points of the leaves, which were elevated ten or fifteen inches above the ground, and hung over the army marching below. Every now and then one or other of them beat with his forceps upon the leaf, and made the same sort of ticking noise, which he had so frequently observed to be made by the soldier who acts the part of surveyor or superintendent, when the labourers are at work repairing a breach made in one of the common hills of the *Termites bellicosi.* This signal among the marching white ants produced a similar effect; for whenever it was made, the whole army returned a hiss, and obeyed the signal by increasing their pace with the utmost hurry. The soldiers who had mounted aloft, and gave these signals, sat quite still during the interval (except making now and then a slight turn of the head), and seemed as solicitous to keep their posts as

regular sentinels. The two columns of the army joined into one about twelve or fifteen paces from their separation, having in no part been above three yards asunder, and then descended into the earth by two or three holes. They continued marching by him for above an hour that he stood admiring them, and seemed neither to increase nor diminish their numbers, the soldiers only excepted, who quitted the line of march, and placed themselves at different distances on each side of the two columns; for they appeared much more numerous before he quitted the spot. Not expecting to see any change in their march, and being pinched for time, the tide being nearly up, and his departure being fixed at high-water, he quitted the scene with some regret, as the observation of a day or two might have afforded him the opportunity of exploring the reason and necessity of their marching with such expedition, as well as of discovering their chief settlement, which is probably built in the same manner as the large hills before described. If so, it may be larger and more curious, as these insects were at least one-third larger than the other species, and consequently their buildings must be more wonderful, if possible; thus much is certain, there must be some fixed place for their king and queen, and the young ones. Of these species he did not see the perfect insect.

In fine, although the curious and interesting habits and manners which have been here described have been well ascertained and accurately observed, naturalists are not yet agreed as to the true physiological characters of the most numerous of the classes composing these communities. That the two individuals called the king and queen in the preceding pages, are perfect insects, deprived of their wings, seems to be on all hands admitted; and that they are kept for the special purpose of propagation, and honoured as the common parents, is also certain. But the true character of the multitude of workers and soldiers is not so clear. Latreille inferred that the workers of Smeathman consist of the larvæ and pupæ, which later pass into the perfect state, assuming wings, and swarm in the manner already described; and that the soldiers are an order apart, which never assume the perfect state, and are incapable of reproduction. To this, Burmeister objects, that there is no instance in the whole animal world in which the undeveloped young labour for the old; and therefore doubts that the workers can be larvæ or pupæ; to which may be added, that these so-called larvæ still retain their form when the winged individuals appear. Huber also doubts that the soldiers can be properly called neuters, and Kirby thinks they

are probably male larvæ. Westwood suggests that the soldiers as well as the workers remain wingless without changing their form, their development stopping short before arriving at maturity, and thereby some individuals acquire that enlarged head which distinguishes the soldiers, and that the real larvæ of the comparatively few specimens which ultimately become winged, are as yet unknown.

These vague and discordant conjectures of naturalists so eminent, show how much still remains to be discovered of the physiology of the White Ants.

I.—UNITED KINGDOM, DENMARK, &C.

THE SURFACE OF THE EARTH,

OR FIRST NOTIONS OF GEOGRAPHY.

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CHAPTER I.

THE SURFACE OF THE EARTH : 1. Origin of the name.—2. Preliminary knowledge.—3. The distribution of land and water.—4. The undulations of the terrestrial surface.—5. GEOGRAPHICAL TERMS : 6. Islands.—7. Continents.—8. Peninsulas.—9. Isthmuses.—10. Promontories.—11. Capes and headlands.—12. The relief of the land.—13. Plains and lowlands.—14. Plateaux and table-lands.—15. Hills.—16. Mountains.—17. Systems or chains of mountains.—18. Oceans.—19. Seas.—20. Gulfs.—21. Bays.—22. Straits.—23. Channels.—24. Roads and roadsteads.—25. Banks and sand-banks.—26. Reefs.—27. Soundings.—28. Lakes.—29. Rivers.—30. The bed of a river.—31. The banks of a river.—32. Tributaries.—33. Vallies.—34. Watersheds.—35. Delta.—36. Estuaries.—37. Friths. THE GREAT EASTERN CONTINENT : 38. Its extent and limits.—39. Its divisions. 40. The Mediterranean.—41. Relief.—42. Its northern belt.—43. The southern belt.—44. Prevailing mountain chains.—45. Outlines of Europe.—46. White Sea.—47. Norway and Sweden.—48. British Isles.—49. France.—50. Spain and Portugal.—51. Italy.—52. Sicily.—53. Greece.—54. Archipelago.—55. Dardanelles and Bosphorus.—56. The Black Sea.—57. Sea of Azof.—58. The Caspian.

—59. Africa.—60. Its climatological zones.—61. The Tell and Sahara.—62. Valley of the Nile.—63. The central belt.—64. The fourth zone.—65. The southern zone.—66. The coasts.

1. **Origin of the name.**—The division of general instruction to which the description of the surface of the earth has been consigned, is called *Geography*, from two Greek words γῆ (ge) the earth, and γράφω (grapho) I describe.

2. **Preliminary knowledge.**—The globular form of the earth,—its rotation every twenty-four hours on its axis,—its poles and equator, the imaginary lines upon it called meridians and parallels,—latitudes and longitudes by which the positions of places relatively to the equator and to each other are expressed,—the methods of ascertaining these positions for all places,—the division of the globe into the northern and southern hemispheres by the equator, and into the eastern and western hemispheres by the meridian of Greenwich,—have been severally explained in our Tracts on the "Earth" and on "Latitudes and Longitudes." All these points constitute indispensable preliminaries to any clear or satisfactory knowledge of geography, and we shall therefore assume in the present Tract that the reader has already become familiar with them.

3. **The distribution of land and water** on the surface of the globe forms the first step in geographical knowledge. The entire terrestrial surface measures about two hundred millions of square miles. Very nearly three-fourths of this is covered with water. The whole surface would be so if it were uniformly level. But being unequal, some parts being more elevated, and others less so, the water, in obedience to the law of gravity, settles upon the lower levels, leaving the more elevated parts dry. It is thus that the Almighty has "gathered the waters into one place," and made "the dry land appear," and to the "gathering of waters" has given the name *Seas*.

Land is therefore nothing more than the summits and elevated plateaux of vast mountains, the bases of which are at the bottom of the water which thus covers three-fourths of the surface.

4. **The undulations of the terrestrial surface** are extremely diversified and irregular, and since the distribution and outlines of the land are determined by them, the latter are equally various and complicated. The declivities by which these elevated parts slope downwards, determine the lines according to which the waters of the sea wash them, and these outlines give those peculiar forms and characters to the land, the description and knowledge of which forms a large part of geography. A system of terms has been invented by which these various forms are expressed and classified.

5. **Geographical Terms.**—Although these terms do not always admit of rigorous definition, and their application is often more or less arbitrary, they are nevertheless eminently useful, and indeed essential to the acquisition of a general knowledge of geography.

6. **Islands** are tracts of land surrounded by water. The term, however, is generally limited to tracts of not very considerable extent. When very small they are often called *isles* or *islets*.

The distribution of islands is not uniform. In some parts they are thickly clustered together within a limited extent of water. A part of the sea thus sprinkled with islands is called an archipelago,* a name which was first applied to the Ægæan Sea, which separates Greece from Asia Minor, but which has been generalised so as to signify any portion of the waters of the globe having a like character.

Islands are found for the most part in the immediate vicinity of the coasts of much larger tracts of land. In this case they are evidently parts of such tracts, separated from them only by valleys, so low that the sea flows through them. Islands, however, are also sometimes found in groups, sometimes ranged in lines, and sometimes, though not frequently, rising singly and isolated in the midst of the ocean.

7. **Continents** are tracts surrounded by water, whose magnitude bears a considerable proportion to the entire surface of the globe.

It will be easily understood that this distinction between islands and continents, depending only on their comparative magnitudes, must be arbitrary, so long as no exact limit is assigned at which a tract of land surrounded by water ceases to be an island and becomes a continent.

The tract in the southern hemisphere, called *Australia*, was formerly classed as an island. More recently geographers give it the title of a continent.

Besides this, there are only two continents properly so called on the globe, each of which has vast magnitude, the one lying in the eastern, and the other in the western hemisphere.

The Eastern Continent, sometimes called the *great continent*, includes Europe, Asia, and Africa, each of which has received the name of continent, though the whole forms one continuous tract of land, between any two points of which it is possible to pass without crossing a sea.

* Etymologists are not agreed upon the origin of this term; some supposing it to be composed of ἀρχὸς (archos), chief, and πέλαγος (pelagos), a sea, and others of Αἴγαιος (aigaios) and πέλαγος, the Ægæan Sea.

The Western or lesser continent consists of North and South America.

The great or eastern continent, having been known to the ancients, is often called the *Old Continent* or the *Old World.*

The western, having been unknown until its discovery by Columbus in the fifteenth century, is often called the *New World.*

8. **Peninsulas** are tracts, nearly, but not altogether, surrounded by water. The name is composed of two Latin words, *pene*, almost, and *insula*, an island.

9. **Isthmuses** are narrow necks, by which two comparatively large tracts are connected together. Isthmus is a Greek word, having the same signification.

The most remarkable examples of an isthmus are presented by the narrow tracts by which Africa is connected with Asia, and South with North America. The former being called the *Isthmus of Suez*, and the latter the *Isthmus of Panama.* Two towns, bearing these names, are built, one upon the former isthmus, on the coast of the Red Sea, and the other upon the latter, on the coast of the Pacific Ocean.

Peninsulas are often thus connected by an isthmus with the mainlands, to which they belong, but not always so. The name peninsula is given to tracts of land which, though partially surrounded by water, are nevertheless connected with the mainland by tracts much too broad to be entitled to the name of isthmus. Examples of this class of peninsular form are numerous, and among them may be mentioned the part of Southern Europe, which includes Spain and Portugal, called the *Spanish Peninsula* (Map 5.); the part of Italy, south of Lombardy and Piedmont, called the *Italian Peninsula* : the southern part of Greece, called the *Hellenic Peninsula* (Map 6); India, and numerous other similar masses of land, projecting in a pointed form into the sea (Map 7).

10. **Promontory** is a name given to a tract of land, of greater or less elevation above the level of the sea, which juts out from a comparatively large extent of land, and which therefore is peninsular in its form. The term, however, is usually applied to tracts of less extent than those which are denominated peninsulas.

11. **Capes and Headlands** are promontories having considerable elevation, so as to be visible from a great distance at sea.

12. **The Relief of the Land** has received different denominations according to its varying elevation above the general level.

13. **Plains and Lowlands** are parts of the land not much raised above the level of the sea, having considerable extent.

Various names are given to such tracts according to the language of the country and their condition in respect to vegetation. Thus an extensive sandy plain, destitute of all vegetation, is called a *Desert;* an example of such a plain on an immense scale is presented by the *Desert of Sahara*, in the North of Africa. Such plains are called *Landes* in France, *Steppes* in Russia, and *Llanos*, *Pampas*, *Selvas*, *Savannahs*, and *Prairies*, according as they are more or less covered with vegetation, in North and South America.

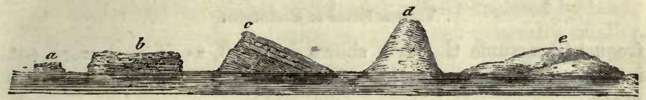


Fig. 1.—Forms of Plateaux, Hills and Mountains.

14. **Plateaux and Tablelands** are extensive level tracts, placed at considerable elevations above the level of the sea, or the general level of the surrounding country, *a b*, fig. 1.

15. **Hills** are elevations not exceeding about 1000 feet in height above the plain at their base, and having an outline variously formed; rounded, *e*, fig. 1.; ridged, *d*, fig. 1, or peaked, as *c*, fig. 1, and fig. 3.

Fig. 2.—Groups of Mountains.

16. **Mountains** are elevations generally exceeding 1000 feet in height, and likewise subject to a similar variety of forms, as shown in fig. 2.

The application of these terms "hills" and "mountains" is very arbitrary, elevations which receive the name of mountains in one place being lower than those called hills in another.

The forms of mountains are very various, and have an important relation to their external structure. Geologists are often able to determine the character of the rocks of which they consist by their outline. Thus, when the outline is characterised by needles rising to considerable elevations, as in fig. 4, the mountainous mass consists of the rocks called Gneiss. Such peaks, which are frequent upon the chain of the Alps, are called *needles*, *teeth*, and *horns*. Mountains are sometimes columnar in their

structure, as in fig. 5, resembling fortifications seen from a distance. In this case they are usually formed of calcareous, that is, limestone rocks. Mountains composed of the same rocks also

Fig. 3. Fig. 4. Fig. 5. Fig. 6.

Various forms of Mountains.

frequently assume the form shown in fig. 6, as if they were cut into steps forming a series of horizontal stages one above the other.

Mountains which assume the peaked or conical form, with a cavity or cup-like depression at their summits, are always of volcanic origin.

Fig. 7.—Barren Island in Bay of Bengal.

In fig. 7, an example of this is presented in the case of Barren island in the Bay of Bengal, consisting of a volcanic cone, 1848 feet high, which is frequently in a state of eruption, surrounded by other peaks of similar formation.

17. **Systems or Chains of Mountains** consist of series of mountains, of varying elevation and form, which are often continued over the whole extent of a continent.

18. **Oceans.**—The configuration of the sea, determined by the form of the lines in which it unites with the land, necessarily corresponds with the configuration of the land, and such forms are expressed by a system of geographical terms of correlative signification.

What a continent is to the land an *ocean* is to the water. This term, therefore, signifies a vast tract of water, unbroken, for the most part, by any tract of land.

Owing to the peculiar distribution of land and water on the globe, it follows that, strictly speaking, there is but one great ocean, between all points of which there is a continuous water communication. Nevertheless, geographers have found it convenient to divide this vast collection of water nominally into several distinct oceans, as will be explained hereafter.

19. **Seas.**—The term sea is applied to tracts of water one degree inferior in magnitude to the oceans, which are generally limited and enclosed between continents or large islands.

20. **Gulfs** are large inlets of the sea partially enclosed by land.

21. **Bays** are nearly the same as gulfs, but generally smaller. Like other geographical terms, these however are arbitrary and indefinite, some inlets called bays being greater than others called gulfs.

Gulfs and bays are the analogues of peninsulas and promontories.

22. **Straits** are narrow necks of water connecting tracts of greater extent. A strait is, therefore, the analogue of an isthmus.

A strait is often but improperly called by the plural term straits; thus the Strait of Gibraltar is frequently denominated the Straits of Gibraltar.

23. **Channels** are narrow tracts of water flowing between opposite coasts that are nearly parallel, and are much wider than straits.

24. **Roads and Roadsteads** are tracts of water sheltered by adjacent lands from violent or dangerous winds, having sufficient depth for safety, and not too great depth for anchorage. They are stations where vessels are accustomed to lie at anchor.

25. **Banks and Sandbanks** are parts of the bottom which lie so near the surface as to be attended with danger, and in places much affected by tides are often uncovered at low water.

26. **Reefs** are sunken rocks, which rise so near the surface, that the waves in passing over them are broken into foam, which thus render their presence manifest to mariners. In a calm sea, however, as there is nothing to indicate their presence, they are a great source of danger to the navigator.

27. **Soundings.**—The depth of the sea is found by a sounding-line, which is a cord of sufficient length, to the extremity of which a heavy piece of lead is attached. Upon this cord knots are made at intervals of five fathoms, the number of knots counting from the lead being indicated by visible marks. The lead is let down into the sea from the deck of the ship; the sounding-line to which it is attached being coiled round a cylinder, or reel, which turns freely on an axle. Two seamen hold up the reel by handles at the extremity of the axle, while another observes the line passing over the bulwark of the vessel. The

leaden weight sinking in the water draws with it the line, which thus unrolls itself from the reel, and this continues until the lead strikes the bottom. When that takes place the reel ceases to revolve and the line to sink, and the seaman who observes the sounding, notes the number of the knot which is nearest the surface, and thus obtains the depth, which is always expressed in fathoms.

The lead, suspended from the extremity of the sounding-line, is cup-shaped at its lower end, and grease, technically named *the arming*, is put into the cavity, so as to be capable of taking up by adhesion a portion of the shells, sand, or other substance, which is at the bottom, with which it comes into contact. This being drawn up, the navigator is informed not only of the depth, but of the quality and character of the bottom, which often serves him as a guide to his position.

In this manner surveys are made of the bottoms of all seas which are much navigated, and charts are drawn and engraved, upon each part of which is marked the number of fathoms of depth in the corresponding parts of the sea, and frequently the character of the bottom.

It happens fortunately that the general depth of the oceans and open seas is so considerable as to be attended with no danger to navigation. Such charts, therefore, as are here described are only necessary for navigation in enclosed seas and tracts of water near to coasts.

28. **Lakes** are sheets of water, of greater or less magnitude, completely surrounded by land, and having no superficial communication with the sea. They are, therefore, to the water what an island is to the land, and, like an island, the name is generally restricted to magnitudes which are not very great. A lake of great magnitude is generally called an inland sea.

Like other geographical terms, these, however, are arbitrary; some sheets of inland water called seas being less than others called lakes.

29. **Rivers** are large streams of fresh-water, formed by the rain which falls on elevated parts of the land, descending the declivities in streams, which, gradually uniting one with another, form at length a large course of water, which receives the name of a river.

30. **The Bed of a River** is a groove formed in the land, descending in a direction varying with the level of the surface, until it reaches the coast, where its water is discharged into the sea.

31. **The Banks of a River** are the land which confines its course on either side, and are distinguished as the right and left

banks, that which is to the right in descending the river, being called the right bank, and the other the left bank.

32. **Tributaries**, or affluents, are the streams which flow into a river on one side or other of its course. In the larger rivers these tributaries themselves are often considerable rivers, and receive along their course subordinate tributaries.

By reason of the common tendency of water to find the lowest level, rivers flow along the bottoms of valleys, and their winding courses, often very complicated, are determined by the varying direction of these valleys. Their tributaries run along the bottoms of smaller valleys, intersecting that of the principal river at various angles.

33. **The Valley**, along the bottom of which a great river flows, usually receives its name from that of the river, and is often of vast extent; the declivities which form its sides sometimes measuring hundreds, or even thousands, of miles.

34. **Watershed** is the name given to the declivities which thus determine the tributaries of a great river, and the whole extent of the valley is sometimes called the *basin* or hydrographic region of the river.

35. **Delta.**—A great river, in approaching its mouth, often diverges into different channels, forming angles with each other, and thus discharges itself into the sea by two or more mouths. These diverging branches are called a *delta*, from a fancied resemblance, presented by the two extreme branches and the line joining the two extreme mouths, to the Greek letter Δ, delta.

36. **Estuaries.**—The mouths of rivers are often placed in inlets of the sea, where the tide ebbs and flows, so that the waters of the sea alternately enter the mouth of the river and retire from it with the rise and fall of the tide, mixing with the water of the river, and thereby producing a constant state of agitation in the water of such an inlet. The name estuary has accordingly been given to such sheets of water, from the Latin word *æstus*, signifying the agitation of water such as that here described.

37. **Firths.**—The name firth, also written frith, is sometimes given to estuaries; this term, however, is more particularly applied in Scotland. Thus the estuary of the river Forth, which lies between Fifeshire and Edinburgh, is called the Firth of Forth.

The term firth or frith is generally assumed to be taken from the Latin word *fretum*, a strait or narrow neck of the sea. Mr. A. K. Johnson, however, considers it to be derived from the Scandinavian term *fiord*, pronounced *fiurth*, which has the same signification.

The principal terms composing the geographical nomenclature, and expressing the forms affected by the outlines of land and waters, and the forms of relief produced by the varying elevation and depression of the surface of the land, being clearly understood, a general description of the globe we inhabit, as it is diversified by land and water, and by the undulating surface of the former, will be easily rendered intelligible.

II.—ARABIA AND PERSIA.

THE GREAT EASTERN CONTINENT.

38. **Its extent and limits.**—This vast tract has an oblong form, as already indicated; its extreme length being somewhat more than twice its extreme breadth. It is included between 20° west and 190° east longitude, and between 35° south and 75° north latitude. Nearly its whole extent lies therefore in the northern part of the eastern hemisphere. A small portion of the north-western part of Africa, including Morocco, juts into the western hemisphere, and the southern promontory of the same division of the great continent, terminating in the Cape of Good Hope, projects into the southern hemisphere.

This continuous tract of land consists, as is well known, of three unequal divisions, which, though not detached one from another by sea, have received the name of continents. The smallest of

these in magnitude, but transcendently the most important in its social and political character, is EUROPE, which occupies the northwest corner of the great continent, being separated from Africa by the Mediterranean Sea, and from Asia by a low chain of mountains called the Ural, a river of the same name, the Caspian Sea, a great sheet of inland water, into which this river discharges itself, and the Black Sea.

39. **Its divisions.**—If the whole superficial extent of the great continent be supposed to consist of eight equal parts, the area of Europe will be one of these parts, that of Africa three, and that of Asia, which covers the remainder, four.

Africa is divided from Europe by the Mediterranean Sea, and from Asia by the oblong tract of water, directed N.N.W. and S.S.E., called the Red Sea. This sea is connected with the Indian Ocean, lying to the east of Africa, and the south of Asia, by a narrow neck of water, called the Strait of Bab-el-Mandeb.

40. **The Mediterranean** sea, which forms one of the most important features in the western part of the great continent, lies in a direction nearly east and west, and communicates with the Atlantic Ocean by a narrow neck of water, interposed between the southern point of the Spanish peninsula, and the north-western corner of Africa, called the Strait of Gibraltar, from the rock of that name at the point of Spain.

41. **Relief.**—The relief of the surface of the great continent is characterised by an elevated ridge, the general direction of which is parallel to its longitudinal axis, and is consequently E.N.E. and W.S.W. very nearly, but the summit of this ridge is much nearer to the southern than to the northern coast of the continent, so that it divides its area very unequally. The declivity, therefore, which slopes to the southern coast, is much more rapid and shorter than that which extends to the northern coast.

42. **Its northern belt.**—The northern division consists of a great belt of flat surface, beginning with the plains of Holland at the west, and terminating with the deserts of Siberia at the east, being only interrupted by the chain of Ural Mountains, running north and south at the confines of Europe and Asia. Except where human industry has redeemed it, and brought it under cultivation near its western extremity, the characteristic of this plain is that of marshiness and insalubrity.

43. **The southern belt.**—The more limited plain south of the ridge-summit, already mentioned, commences at the west with the great African desert of Sahara, and stretches with little interruption across Arabia, Persia, and Northern India, to the shores of Kamtschatka.

44. **Prevailing mountain-chains.**—The various mountain-

chains, the combination of which forms the main ridge of the great continent, commence with Mount Atlas and the Pyrennees at the extreme west, and are continued by the Alps and the Himalaya to the Altaic mountains at the extreme east.

45. **Outlines of Europe; their adaptation to Commerce.**—The most striking geographical feature by which Europe is distinguished from the other parts of the great continent, consists in the numerous and extensive inlets of water by which it is penetrated and intersected in all directions. No equal extent of land in any part of the globe presents a like phenomenon, and to this, as much as to its temperate climate, must undoubtedly be ascribed the immense social, commercial, and political predominance which it has acquired and maintained. By this reticulation of inland seas, gulfs, bays, and straits, navigation and commerce arrive within short distances of all its internal centres, and its vast extent of coasts is studded with cities and towns, and sheltered ports and harbours, which become so many emporiums of commerce, and centres and sources of wealth and civilisation.

46. **White Sea.**—At its extreme north, Europe is penetrated by an enclosed sheet of water of great magnitude, called the White Sea. On the west, the Baltic enters it, ramifying in different directions, throwing out north and west the gulfs of Bothnia and Finland, and sprinkled with islands and vast peninsulas, which form kingdoms of great importance, such as Denmark.

47. **Norway and Sweden** are formed into a great peninsula, separated from the continent by a broad neck of land, included between the North Sea on the west, and the head of the Gulf of Bothnia on the east.

48. **British Isles.**—Nearly opposite the mouth of the Baltic, and the north-western point of France, are placed the British Isles, separated from the coast of Holland and Belgium by the German Ocean, and from that of France by the English Channel and the Strait of Dover. These islands, combined with the subordinate ones with which they are surrounded and skirted, such as the Shetlands, the Orkneys, the Western Isles, the Isles of Man and Anglesea, the Scilly, and the Channel Islands, may be considered as forming an archipelago, the principal divisions of which are richly intersected by channels, bays, and gulfs, which have so favoured navigation, as to enable the British nation to attain and maintain that commercial and naval pre-eminence, for which she has so long been celebrated.

49. **France**, the most important and powerful of the European states, occupies the centre of Western Europe. Her territory is separated on the east from those of the German states by the Rhine,

from that of Switzerland by the chain of the Jura, from Italy by the Alps, from Africa by the Mediterranean, and from Spain by the Pyrenees. On the west it is limited by the Atlantic, and on the north, in the absence of any natural boundary, is divided from Belgium by a frontier settled by political conventions.

50. **Spain and Portugal** occupy a portion of land having the peninsular form, the neck by which it is connected with the continent extending from the Bay of Biscay to the Gulf of Lyons, and being traversed by the chain of the Pyrenees. This neck of land, so much narrower than the general width of the Spanish peninsula, is nevertheless much too wide to entitle it to the name of an isthmus.

In the geography of Europe the tract thus occupied by Spain and Portugal is usually called the **Peninsula,** without other designation.

51. **Italy.**—The southern part of Italy projects into the Mediterranean Sea in the form of an oblong tract of land, having at its southern extremity a smaller tract nearly at right angles to it; the outline of the whole presenting a striking resemblance to a boot. The Italian territory, however, occupies a wide extent of land north of the boot, enclosed on the north by the chain of the Alps. This northern part of Italy includes the territories of Venice and the Milanese, called Lombardy, at present part of the Austrian empire, and the kingdom of Sardinia. That part of the Italian territory forming the boot, being nearly surrounded by water, with the Adriatic on one side and the Mediterranean on the other, is distinguished as the Italian Peninsula.

52. **Sicily.**—Immediately at the toe of the boot, and separated from it by a narrow neck of water, celebrated in history as the Strait of Messina, is the fertile and beautiful island of Sicily, one of the most remarkable features of which is the volcano called Mount Etna.

53. **Greece** projects into the eastern end of the Mediterranean, having, like Italy and Spain, the peninsular character. These three tracts have been noticed even by ancient geographers as the Spanish, Italian, and Hellenic peninsulas.

54. **Archipelago.**—The arm of the Mediterranean which, turning to the north, intervenes between the Hellenic peninsula and the coast of Asia Minor, thickly sprinkled with islands, is the Archipelago or ancient Ægæan Sea, from which all other tracts of water of a similar character have taken their name.

55. **Dardanelles and Bosphorus.**—The Archipelago is connected with the great inland sea, called the Black Sea or the Euxine, by a narrow neck of water, consisting of two straits, between which lies a wider strip of sea. The strait which is next

the Archipelago is called the Dardanelles, the ancient Hellespont; and that which is next the Black Sea, the Bosphorus; the intermediate water being called the Sea of Marmora.

56. **The Black Sea** is nearly enclosed by land, but communicating through the Bosphorus with the Archipelago and the Mediterranean, it cannot properly be considered as a lake. Its water is, nevertheless, much less salt than that of the ocean, and it is consequently more readily frozen. Its depth near the shore varies from 24 to 220 feet, and in the middle is more than 1000 feet.

57. **Sea of Azof.**—This sea communicates with a smaller one north of it, called the Sea of Azof, by a narrow neck of water, called the Strait of Yenekali. A tract of land nearly surrounded by the waters of the Black Sea and the Sea of Azof, and connected with the continent by a narrow neck of land, is called the Crimea; the connecting neck being called the Isthmus of Perikop. This peninsula has been celebrated for the fortress of Sebastopol erected by Russia near its southern extremity, and destroyed in 1855 by the allied armies of France and England.

58. **The Caspian.**—Near the southern confines of Europe and Asia is the largest lake in the world, called the Caspian Sea. Its water is salt, but much less so than the ocean, and it is shallow, even at its centre, the depth not exceeding 300 feet. That it can have no immediate and uninterrupted subterranean communication with the Black Sea, which is near it, is proved by the fact that the level of its surface is 82 feet below that of the latter sea.

59. **Africa** is an immense triangular-shaped tract of land, the base of which is presented towards the north, and the point to the south. Its coast is everywhere nearly uniform, and entirely destitute of those indentations for which Europe is so remarkable. It projects southwards into the great ocean, which it divides into two regions, of which the western is called the Atlantic, and the eastern the Indian Ocean. As has been already stated, Africa is separated from Asia by the Red Sea, except at the point where they are connected by the narrow isthmus of Suez.

This division of the great continent is, beyond all comparison, the most uncivilised and desert portion of the globe. It includes a vast range of country, extending from the northern to the southern tropic, and lying, therefore, altogether in the torrid zone. By reason of the great extent of desert of which it consists, the insalubrity of its climate, and the barbarous character of its inhabitants, it is little known to Europeans.

60. **Its Climatological Zones.**—It may be considered as consisting of a succession of zones, separated by parallels of latitude, having different physical characters.

61. **The Tell and Sahara.**—The northern zone, included between the ridge of Mount Atlas and the Mediterranean, is a band of fertile country, generally called the *Tell*, probably from the Latin word *tellus*, the earth. South of this is a vast band, running east and west, about 1800 miles broad, comprising Sahara or the great desert. This extensive surface consists of tracts of sandy and stony soil, rarely producing vegetation, and, when it does, of the most scanty description, with the exception of certain spots appearing here and there in this ocean of desolation, like islands of fertility. These are called Oases, and depend for their productiveness on local springs.

62. **Valley of the Nile.**—On the west this desert not only descends to the verge of the ocean, but is continued with the same character for many miles beneath its surface and beyond the coast. On the east, it descends by a series of sterile terraces to the valley of the Nile, where the soil suddenly acquires a high degree of fertility, which character it retains throughout the whole extent of country between the Nile and the Red Sea. The entire valley of the Nile, from the skirt of the Desert to the Delta, and from the right bank of the river to the Red Sea, has been celebrated in ancient history for its general fertility, a character, nevertheless, which is not altogether without exception, an example of which is presented in the tract over which the route between Cairo and Suez is conducted.

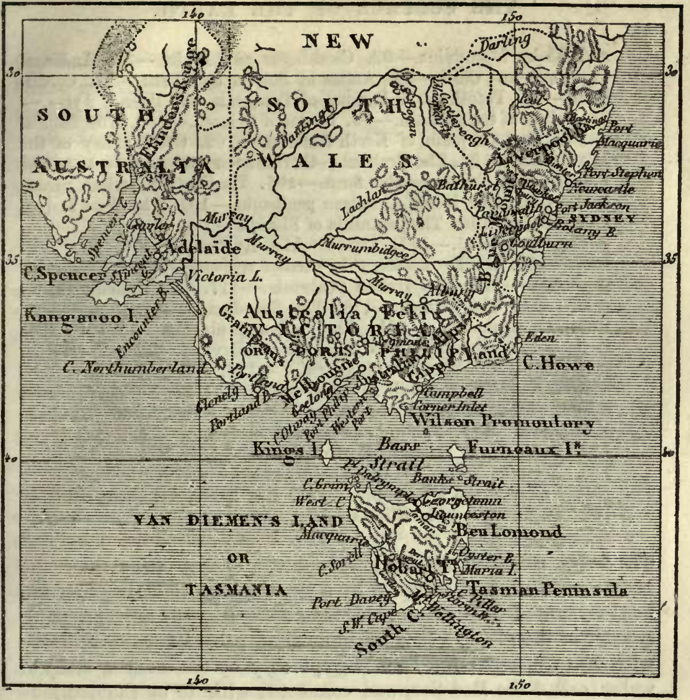
63. **The central Belt** of Africa, immediately south of the great desert, has quite a different character, being both fertile and populous.

64. **The fourth zone,** lying south of this, is almost unknown, except on its seaboard. It is supposed to consist of an extensive and elevated table-land, with lofty mountain-ranges rising out of it, from which character it is distinguished in geography as High Africa.

65. **The southern zone** of the great African peninsula consists of a triangular area, the vertex of which projects into the Southern Ocean, and is terminated by the celebrated Cape of Good Hope. This part is diversified by hill and valley, and is naturally fertile, supplying extensive pasturages. The native tribes which inhabit it are the Hottentots and Caffres. The English colony, originally Dutch, has been generally confined to the southernmost part of the angle, but has a constant tendency to push their territory further north, thereby coming into contact, and frequently into conflict, with the natives.

66. **The coasts.**—It has been already observed that the coasts of Africa are singularly destitute of all projections and indentations, and, consequently, ill-adapted for commerce. For the

same reason, there is a remarkable absence of those numerous islands which enrich all coasts deeply indented, which considered in their physical character are in fact parts of the mainland, separated from it by valleys so deep as to allow the sea to flow through them. Madagascar, on the east coast, is the only African island. There are a few islands of much less magnitude, called the Comano Islands, between Madagascar and the coast. Most of the other islands which appear in the Indian Ocean are too distant to be regarded as mere appendages of Africa.



III.—AUSTRALASIA.

THE SURFACE OF THE EARTH,

OR FIRST NOTIONS OF GEOGRAPHY.

CHAPTER II.

67. Asia.—68. Its Plateaux.—69. The eastern Plateau.—70. Its physical character.—71. The western tableland.—72. British India : Dekkan plateau.—73. Australia.—74. Australasia. — 75. Polynesia.—76. British Colony : its territory and physical features.—77. Its climate. —78. Vegetable productions.—79. The indigenous animals.—80. Minerals : Gold.—81. Aboriginal tribes. THE WESTERN, OR NEW CONTINENT. — 82. Its extent and form. — 83. Divisions : South America. — 84. Central America. — 85. North America. —86. Its extent and limits. —87. Its political divisions. — 88. Gulf of Mexico and Caribbean Sea.—89. Relation between the coasts of the old and new continents.—90. The relief.—91. Chippewayan

called by modern geographers Australasia, being the most considerable tracts of land in the southern latitudes. The various islands sprinkled in countless numbers over the Pacific Ocean, comprising Australasia itself, have received the general name of Oceania.

75. **Polynesia.**—Those which lie between the Indian Archipelago and the western coast of America, taken collectively, have been called *Polynesia.*

76. **British Colony; its territory and physical features.**—From the circumstance of the recent gold discoveries, and the consequent emigration from the United Kingdom to Australia, this colony has acquired a greater interest than any which its mere geographical pretensions could claim for it. It may therefore be desirable here to notice its physical character and conditions.

Notwithstanding the immense immigration which has taken place, and the excitement attending the mineral researches, of which it has become the theatre, the surface of this great island has been but very imperfectly explored. One of the most remarkable and geographical characters it presents is the complete absence of large navigable rivers, and the uniform outline of its coast, which has no indentations forming bays, gulfs, or other inlets. It is surrounded by a chain of mountains, the summit-ridge of which is from 30 to 40 miles from the shore. The chain running along the eastern coast, which is best known, is called the Australian Alps at the extreme south, the Blue Mountains near Sidney, and the Liverpool chain towards the north. From the slopes of these mountains a few small rivers descend, which are so inconsiderable as to be nearly dry in summer. The interior consists of a series of low plains, which include good pasturages, and large tracts covered with sand and shells, which have an appearance such as would be presented by a surface from which the sea had recently retired. Some considerable streams have been seen in the interior, but whether they flow into an inland sea like those which run into the great Asiatic lake, or are absorbed by the sands, has not been ascertained.

One of the most curious physical characters connected with this island is the existence on its north-eastern coast, at a distance of from 20 to 70 miles, of the longest coral reef in the world, measuring about 1200 miles in length, and rising out of the bosom of a sea said to be fathomless. The breadth of this reef varies from a few hundred yards to several miles.

77. **Its climate.**—When it is remembered that the extreme latitudes of Australia are 15° and 40°, it may be expected that its climate must be mild and salubrious. With a drier atmosphere it has all the thermometric characters of Southern Italy. The

vegetation seems to be maintained by the deposition of dew, for it often happens that intervals of several years elapse without rain. When rain does occur, however, it is periodic, and prevails through three months.

78. **Vegetable productions.**—The natural vegetable productions are neither considerable nor useful; there is no species of edible fruit. The trees composing the woods appear to be of one uniform family, the foliage being scanty and almost shadowless. On the other hand, transplanted vegetation is easily naturalised. Districts are found adapted to the cultivation of all sorts of grain; but, for the present, the most advantageous employment of the soil is for pasturage.

79. **The indigenous animals** are few, being mostly of the family of marsupia, such as the opossum and kangaroo. The most remarkable and anomalous of these animals is one called the ornithorhynchus, which is a sort of connecting link between birds and quadrupeds, having the bill and feet of a duck, and the body and fur of a mole.

80. **Minerals—Gold**—It is well known that gold in large quantities is found in this region. It may be added, however, that coal and iron also exist there in inexhaustible quantities, as well as marble, lead, and copper.

81. **Aboriginal Tribes.**—The native tribes, which appear to prevail in but limited numbers, are in the lowest state to which nature can sink. They are generally nomadic, but sometimes build rude villages, and subsist by fishing on the coast.

So utterly degraded is their condition, moral and physical, that many tribes are unprovided with clothing, practise cannibalism, and are wholly destitute of social and religious ideas.

THE WESTERN, OR NEW CONTINENT.

82. **Its extent and form.**—Like the great eastern continent, the western is an oblong tract of land, the length of which intersects the parallels of latitude obliquely, being directed first from the S. S. E. to N. N. W. and then turning eastward in approaching the pole. It extends from 50° S. lat. to the utmost limit of polar discovery.

83. **Divisions—South America.**—This continent consists of two peninsulas, connected by a narrow tract of considerable length. The southern peninsula resembles Africa in its general outline, having a triangular form, with its base towards the north, and its vertex to the south. It also resembles the African continent in having coasts but little indented by bays or gulfs,

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but differs from it in being intersected by large and extensive rivers.

84. **Central America** is the tract of land uniting South America with the northern peninsula. Its southern part being not more than 30 miles wide, is denominated the isthmus of Darien or Panama, a town of the latter name being on its western coast.

IV.—UNITED STATES—CANADA.

85. **North America,** like Europe, is indented with numerous bays, and its northern division has the largest collections of fresh water in the world, consisting of five extensive lakes,—called Superior, Michigan, Huron, Erie, and Ontario, which communicate with each other, and discharge their water through the River St. Lawrence into the gulf of that name.

86. **Its extent and limits.**—North America is separated from Asia by Behring Strait on the west, and from the large island of Greenland by Baffin's Bay and Davis's Strait on the north and east.

A sort of northern archipelago intervenes between this continent and Greenland, into which numerous promontories project, and the waters of which are variously denominated, the largest of these inlets being Hudson's Bay.

87. **Its political divisions.**—In political geography North

America consists of several divisions, the central part being the United States, the north-eastern British America, the north-western angle near Behring Strait, Russian America, and the part forming the southern point, Mexico.

88. **Gulf of Mexico and Caribbean Sea.**—The large inlet of the ocean enclosed between the northern coast of South America, the southern coast of North America, and the eastern coast of Mexico and Central America, consists of the Gulf of Mexico and the Caribbean Sea, its eastern part, sprinkled with the West Indian islands, forming an archipelago.

89. **Relation between the coasts of Old and New Continent.**—It has been observed by Humboldt, that on comparing the eastern coast of South America with the western coast of Africa, the same correspondence is observed between them as is usually seen in the opposite sides of a valley or ravine; from which he argues that the bottom of the Atlantic, which flows between these continents, ought to be regarded as an extensive valley, the sides of which, rising to an elevation above the level of the water which fills it, form the coasts of the two continents. Thus the concavity on the African coast, called the Gulf of Guinea, has a corresponding convexity on the South American coast forming the territory of Brazil, and the convexity at the north-western corner of Africa, of which the coast of Morocco forms a part, corresponds with the opposite concavity formed by the Caribbean Sea and the Gulf of Mexico. So that if the two continents were moved towards each other, and brought into contact, their coasts would fit into each other, like the dove-tailed edges of carpentry. The Atlantic, following the course of this submarine valley, entering between the Cape of Good Hope and Cape Horn, flows first in a northerly direction, a little towards the east, next, after passing the Gulf of Guinea, in a north-westerly direction, and finally, after passing the north-western coast of America, in a north-easterly direction.

90. **The relief** of the western continent is characterised by a continuous ridge of considerable elevation, which traverses it longitudinally from its northern to its southern limit, lying much nearer to the western than to the eastern coast.

91. **Chippewayan and Rocky Mountains.**—The part of this ridge or mountain-chain which traverses North America, commencing at the Frozen Ocean, is called in its northern division the Chippewayan range, and in its southern division by the better known name of the Rocky Mountains.

92. **Cordilleras and Andes.**—After passing along Central America, this ridge takes the name of the Cordilleras and Andes, and rising to much greater heights, and throwing up vast peaks

which are frequently volcanic, it is continued in a direction parallel to the western coast of the continent, until it terminates in the Tierra del Fuego, the southern point of which is called Cape Horn.

93. **Andes of Patagonia and Chili.**—Between this point and Chili, returning northwards, the slopes of the Andes descend to the waters of the Pacific, the coast being lined with numerous islands and indented with arms of the sea, an outline which indicates the continuation of the mountain range below the waters of the ocean; the capes, promontories, and islands being merely the ridges and summits of the spurs and peaks of the main range, whose bases are established at the bottom of the ocean. Proceeding northward, the general direction of the chain takes a more inland course, leaving between its base and the sea a long and flat tract of land, whose coast is no longer broken by the indentations just described, is completely destitute of islands, and forms no shelter for navigators.

94. **Andes of Bolivia and Peru.**—Still proceeding northward and approaching the Peruvian territory, the general elevation of the Andes rapidly increases, and their summits rise to vast elevations above the snow-line; among these is the Nevado Aconcagua, having an elevation of 24000 feet, and being the most lofty point of the western continent. This peak was originally volcanic, but within historic record it has not been active.

About latitude 24° south, the chain takes the name of the Peruvian Andes, and here it is at a considerable distance from the western coast, from which it is separated by a sandy desert.

95. **Cordilleras.**—North of 21° lat. south, the chain of the Andes diverges into two or three separate ridges, called Cordilleras, which are connected at different points by their common spurs issuing transversely to their directions, so as to form a net-work enclosing numerous valleys, the bottoms of which are elevated to a considerable height above the level of the sea, forming in many cases plateaux and tablelands of great extent, the most remarkable of which is that of Desaguadero, which measures 400 miles in length, with a breadth varying from 30 to 60, and a general elevation of nearly 13000 feet above the level of the sea. Vast peaks are thrown up from the borders of this immense plateau to the height of more than 8000 feet above the surface, rising far above the snow-line.

96. **Potosi.**—Upon this extensive tableland, whose area is three times that of Switzerland, stands Potosi, the highest city in the world, at an elevation of 13330 feet above the level of the sea, with a population of 30000. This city is built on the

northern declivity of a mountain called Cerro de Potosi, which is rich in mineral veins, and especially in silver.

97. **Pampas of Patagonia and Buenos Ayres.**—Since, as has been explained, this great chain runs close to the western coast, it may be expected that a vast tract of plains, or lower lands, must extend from the foot of its eastern declivity to the eastern coast of the continent. This tract in South America is covered with the deserts and pampas, as they are called, of Patagonia and Buenos Ayres, the surface of which is sandy and marshy, or saline, producing nothing but a scanty pasture and stunted trees.

98. **Selvas of Amazon.**—Another portion, consisting of the valley of the great River Amazon, called Selvas, consists of a space of more than two millions of square miles, a part of which is covered with natural forests, and the remainder with grassy pampas.

99. **Llanos of Orinoco.**—The valley of the Orinoco, another division, is characterised by vast flat lands, called Llanos, covered with long grass, interspersed here and there with palm trees, used by the traveller in these inhospitable regions as landmarks.

100. **Alleghanies.**—Extensive lowlands stretch in like manner over North America, between the chain of the Rocky Mountains and the eastern coast. This division of the continent is also intersected in a direction parallel to the Rocky Mountains, and nearer to the Atlantic by a chain of much lower hills called the Alleghanies, which, like the former, extend from the Gulf of Mexico to the Arctic Ocean, enclosing an area of more than 3,000000 of square miles.

101. **Eastern Plain of North America.** — Between the chain of the Alleghanies and the Atlantic coast is another plain parallel to the former, of nearly equal length from north to south, but of less width. The eastern coast is indented and fringed with numerous bays and creeks, which favour commerce and navigation.

102. **Great Valley of the Mississippi.**—The extensive valley lying between the chain of the Alleghanies and the Rocky Mountains is drained by the Mississippi, the largest and most important river in the world, next to the Amazons, which, nevertheless, it exceeds in length, though inferior to it in the extent and number of its tributaries.

103. **The Prairies.**—Among the features which characterise the land in the western continent, and more especially in its northern part, the Prairies demand especial notice. These are vast plains, generally covered by deep herbage, and which form a level so dead and uniform, that it is impossible to resist the

impression that they must have been once the bottoms of large sheets of water, since nothing but sedimentary deposition could produce a level so uniform. The extent of many of these plains is so great, that in traversing them points may be attained from which all the surrounding country will cease to be visible, so that the prairie presents to the observer a circular horizon, like that witnessed at sea from the deck of a ship.

As there are, in general, no roads or paths traversing these vast plains, the traveller who ventures across them can only guide his steps by a compass, or by the stars.

OUTLINES OF THE LAND.

104. The prevalence of the peninsular form with the pointing southwards is one of the most remarkable features in the configuration of the land. The angular point is also generally succeeded or surrounded by one, or several islands; and where such islands are not apparent, the tendency towards their formation is discoverable by the soundings, which prove the existence of shoals in the places where such islands would otherwise be apparent. A general view of the map of the world will strikingly illustrate these observations.

105. **The South American Peninsula** is an example of such a form upon a grand scale. Like all the other forms of this class, it is a triangle, having its base presented towards the north, and its vertex jutting into the Southern Ocean, where it terminates in the point called Cape Horn.

Its apex is broken by the ocean into a multitude of islands, the largest of which, separated from the main-land by the Straits of Magellan, is called the Tierra del Fuego, or land of fire, from several volcanic peaks which rise from it to the altitude of 4000 feet. The southernmost island of the Fuegian archipelago terminates in the headland, or promontory, so well known as Cape Horn.

106. **The North American Peninsula** has a like form, its southern point being Mexico; but instead of terminating in the ocean, it is united with the South American peninsula by a tract of land called Central America, which, taken as a whole, may be regarded as an isthmus, although geographers have, in this case, limited that name to its southernmost and narrowest part, called the Isthmus of Panamà.

107. **The West Indian Archipelago** stands in the same relation to the North American peninsula as the Fuegian archipelago to the southern peninsula. This group of islands, celebrated as being the theatre of the great discovery of Columbus, is included

in the tract of water enclosed between the northern coast of South, and the southern coast of North, America. When Columbus undertook his voyage, his purpose was to sail to India round the western hemisphere of the globe, and when he arrived at the island of St. Salvador, one of the Bahama group, he imagined that he was on the coast of India; and hence this, and the other islands of the archipelago subsequently discovered, came to be called the West Indies: they are, however, more commonly denominated by French and foreign geographers the Antilles.

The extensive tract of sea enclosed by the coasts of North and South America, and the chain of West Indian Islands, is denominated the Gulf of Mexico, and the Caribbean Sea; the former being included by the southern coast of North America, and the northern of Central America, and the latter by the northern coast of South America, the West Indian Islands, and the eastern coast of Central America.

108. **The Peninsula of Florida** presents another example of the like form. It is the southernmost point of North America, jutting into the ocean between the Atlantic and the Gulf of Mexico, and terminating in Cape Sable, directly north of the well-known harbour and city called Havannah, in the island of Cuba.

109. **Lower California** has the same peninsular form, directed southwards. It lies on the western coast of Mexico, from which it is separated by an inlet of the Pacific, called the Gulf of California. It is terminated at its southern point in a headland called Cape St. Lucas.

110. **Greenland**, in the extreme north, presents an example of similar formation, being formed into an acute angle, jutting out into the Atlantic towards the south.

111. **Africa**, in the Old World, is a stupendous example of the same peninsular outline. Like South America it is triangular, the base being presented to the north, and the vertex to the south. There are no islands below its vertex, but the tendency to the formation of one is indicated by the shoal called the Lagullas Bank, well known to mariners.

112. **Australia** has a similar form, terminating with the island now called Tasmania, and formerly known as Van Diemen's Land.

113. **New Zealand**, on a much smaller scale, presents a like example, terminating with an island called New Leinster.

114. It is very remarkable that this tendency to the peninsular form with a southern vertex, not only prevails in the continents, but is discoverable equally in the more minute outlines of the land which determines the shores of gulfs, bays, and inland seas.

115. **The Spanish Peninsula**, including Portugal, is an ex-

ample of the same prevailing form, its southern apex being marked by the celebrated rock of Gibraltar, separated from the northern coast of Africa by the narrow neck of water called the Strait of Gibraltar.

116. **The Italian Peninsula** juts southwards into the Mediterranean, with the islands of Sicily and Malta, and the small archipelago formed by the Lipari Islands, at its southernmost point.

117. **The Hellenic Peninsula** is a like example, terminated by the Morea, and surrounded near its southernmost point by the Ionian Islands.

118. **The Crimea**, in the Black Sea, is a peninsula of like form and position, terminating with a southern vertex near Sebastopol.

119. **The Scandinavian Peninsula** consists of Norway and Sweden, and enclosed between the Northern Atlantic on the west, and the Baltic and the Gulf of Bothnia on the east, presents, like the others, an apex to the south, and Zealand, and other smaller islands, lie off its southern point.

120. **European Peninsula.**—Humboldt observes that Europe itself may be regarded as a great peninsula projecting from Asia, and enclosed between the Mediterranean and Black Sea on one side, and the Baltic and Arctic Ocean on the other.

121. **The Indian Peninsula** juts into the ocean southwards, having, like the others, a triangular form, and the island Ceylon off its southern apex.

122. **Further India.**—The tract of land called Further India, lying to the south of China, and including Cochin China, Siam, and Burmah, is another example of like form, terminating in the Malayan promontory with Singapore at its apex, and the Indian archipelago around its point.

123. **Hemisphere of most Land.**—There is a certain hemisphere of the globe within which nearly the whole of the land is included, the middle point of which is at the south coast of England. If an observer were elevated directly above this point, so as to obtain a bird's-eye view of the earth, he would see the whole of Europe, Asia and Africa, North America, and the chief part of South America, all comprised within the visible hemisphere: the only parts of the land which would be included within the hemisphere beyond his view would be the southern point of South America, Australia, and the islands of the Indian Archipelago.

In Map 8, we have given these two hemispheres, having reproduced them from the Physical School Atlas of Alexander Keith Johnston, a work which we strongly recommend to students to aid them in comprehending this tract.

RIVERS.

124. **Formation of Rivers.**—The origin of all rivers is the evaporation of the ocean. The surface of the oceans and seas has an extent, as has been already explained, equal to nearly three-fourths of the whole surface of the globe. This extensive mass of water is subject to an incessant process of evaporation. In this process, the pure water is separated from the salt and other solid matter which it holds in solution. The vapour, therefore, which ascends into and mixes with the atmosphere, is that of pure fresh water. Being lighter bulk for bulk than the air, it rises into the higher regions, where it is transported in different directions by atmospheric currents. By the operation of temperature and electricity, it is converted into clouds, which, attracted towards the most elevated points of the land, collect in dense masses around the ridges and summits of the mountains, where, being condensed and reconverted into water, and sometimes congealed, it is precipitated in the form of rain or snow. From these heights it descends by the common principle of gravitation, either along the surface of the declivities, or through the fissures and interstices of the soil, finding its way to the lower levels; and, following these in their devious and winding course, it at length returns to the sea, with which it mingles, to be again evaporated and sent once more through the same series of physical changes.

125. **Effect of a single ridge.**—When a tract of country, bounded on either side by the sea, is traversed by an elevated ridge or chain of mountains, the rain and snow deposited upon them descends in streams along their slopes at either side, forming at first rivulets, which, coalescing, swell into larger streams, and acquire the character of rivers. These, following the declivities and winding through the valleys, find their way on the one side or the other to the sea. In this case, the general direction of the rivers will be at right angles to the ridge which traverses the country. The rapidity of their streams will be proportionate to the steepness of the declivity, and their length to the distances of the prevailing ridge from one or other coast.

126. **Example in the Eastern Continent.**—An example of the play of this principle is presented in the great eastern continent, where, as has already been explained, the mountain-chains running from west to east are much nearer to the southern than to the northern coast. The rivers, therefore, which flow towards the south, are generally shorter and more rapid, while those which flow towards the north, passing over exten-

sive tablelands and plains having little declivity, are comparatively long and sluggish.

127. **Example in South America.**—South America presents a similar example. The chain of the Andes traversing the country north and south, and much nearer to the western than the eastern coast, gives a similar character to the rivers, those which flow to the west being short and rapid, and those which flow to the east being longer and slower.

In the northern part of South America, the principal mountain chain, diverging into several distinct ridges of the Cordilleras, produces a complicated system of ravines and valleys, which divert the course of the waters in various directions, so that many of the rivers flow northwards and north-westwards into the Caribbean Sea.

128. **Effect of Parallel ridges.**—When a tract of country is traversed by two ridges in nearly parallel directions, their declivities, which look towards each other, form a valley of greater or less width. The rain precipitated upon these slopes, collecting in streams, descends from either side to the lowest point of the valley where they coalesce, and settling into a bed or channel, flow along the lowest level of the valley, forming a river whose course is parallel to the general direction of the bounding ridges, and which continues its course until it discharges its waters into the sea.

In ascending a river, it is found, as may be expected, that the quantity of water which flows in it becomes less and less as the distance from its mouth increases. Since the total collection of water must be proportionate to the number and magnitude of the tributaries above the point of observation, the higher that point is, the less will the number of such tributaries be, and consequently the less the quantity of water in the main stream.

129. **Chief tributaries considerable rivers.**—In the case of all the great rivers, the principal tributaries themselves are rivers of considerable magnitude and importance, and some which have been classed as tributaries might with greater propriety have been considered as the main stream.

130. **Example of Missouri.**—Thus for example the Mississippi receives as tributaries, streams so important as the Red River, the Arkansas, the Ohio, the Missouri, and the Illinois. Now the Missouri is itself a river of much greater length, width, and depth than that which above their confluence has been denominated the Upper Mississippi, and if, of two confluent streams, the greater be entitled to be regarded as the continuation of the main stream, the river which is now called the Missouri ought to be denominated the Upper Mississippi.

131. It must not be inferred from what has been here stated that the valley of every river is formed by slopes, having declivities obvious to the eye, or limited by chains of mountains of conspicuous elevation. Most commonly it is quite otherwise, the declivities of the valley being so gentle as to be almost imperceptible, and the summits of the ridges, which limit it, having no elevation which entitles them to the name of mountains.

132. **Portage.**—Where the navigation of a river is impeded by waterfalls, rapids, shallows or other natural obstructions, the space over which goods, and sometimes canoes or boats have to be carried, to meet the navigable part of the stream again, is called a *portage*.

133. **Examples of rivers of North America.**—This division of the western continent being traversed by two ridges, the Rocky Mountains and the Alleghanies, whose general directions are nearly parallel, is divided into three zones, running north and south, the centre and broadest of which is included between the two ridges, the eastern zone sloping down from the Alleghanies to the Atlantic, and the western from the Rocky Mountains to the Pacific.

134. **Eastern rivers.**—The disposition of the general relief of the continent, shown by a section of it, running east and west, determines three different directions for the rivers. Those which are formed of the drainage of the eastern slopes of the Alleghanies, flow eastward into the Atlantic, and the distance of the ridge of the Alleghanies from the Atlantic coast not being great, and the surface of the intervening zone being nearly plane, the lengths of the rivers are inconsiderable, and their streams not rapid.

135. **Western rivers.**—In the same manner the drainage of the western slope of the Rocky Mountains forms a series of rivers which flowing westward fall into the Pacific.

136. **The Mississippi and its tributaries.**—The great extent of the valley included between the ridges of the Alleghanies and the Rocky Mountains, and its great capacity for cultivation, confer upon it an importance which is immensely augmented by the great length through which the rivers which traverse it, are navigable.

137. The drainage of the western slopes of the Alleghanies, and that of the eastern slopes of the Rocky Mountains, form two systems of rivers, the one flowing from west to east, and the other from east to west, and meeting in a common bed in the centre of the valley. They thus form a main stream traversing the valley from north to south, the magnitude of which increases as it descends southwards, in proportion to the number and magnitude of the streams which flow into it from the one side or the other. This central stream is the Mississippi, which gives its name

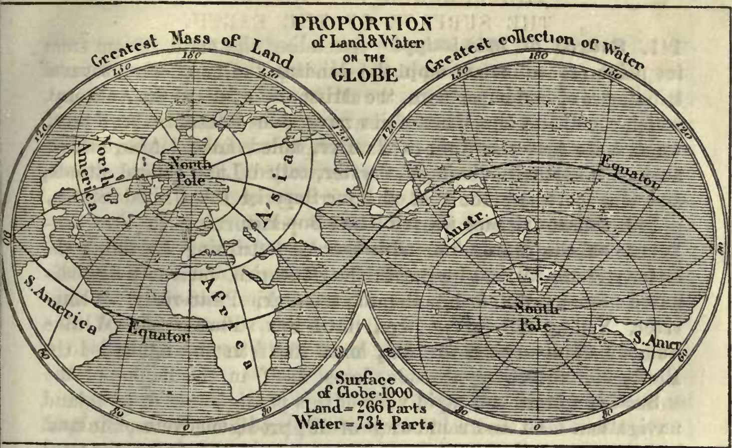
to the entire valley, extending from the Gulf of Mexico, into which its waters fall, to the great northern lakes.

138. **Red River—Arkansas—Ohio.**—New Orleans, which is the port of the Mississippi, is built at the confluence of the arms of its Delta, about one hundred miles above its mouth. Ascending the river from this point, we encounter successively its vast tributaries, the first of which is called the Red River, which flows into it from the slope of the Rocky Mountains upon its right bank. Proceeding upwards, the next is the Arkansas, on the same side, which itself receives at various points of its course subordinate affluents, among which the principal are the Canadian, the Red Fork, the Salt Fork, &c. A little higher, we come to the Ohio, flowing from the east, after having traversed a vast extent of the great valley, and receiving several large tributaries, such as the Cumberland, the Tennessee, the Wabash, &c. The Ohio carries the chief part of the commerce of the states of Tennessee, Kentucky, Virginia, Ohio, Indiana, Illinois, and the western part of Pennsylvania. It washes Pittsburgh, Cincinnati, and Louisville, while its tributaries reach the principal towns of the interior of the adjacent states. It is navigated by steam-boats of the largest class as high as Pittsburgh.

139. **St. Louis.**—Returning to the confluence of the Ohio and the Mississippi, and continuing to ascend the latter river, we arrive at St. Louis, a city of the first importance, and likely one day to become the great capital of the valley of the Mississippi and the western division of the States, with New Orleans for its port. Already we see ranged along its quays hundreds of steamboats of immense tonnage, which ply incessantly between it and New Orleans, carrying down the stream the produce of the interior, and up, innumerable articles of importation.

140. **Illinois.**—Immediately above St. Louis we arrive at a point marked by the confluence of three streams, one flowing from the north-east, one from the north, and the other from the north-west, the last being the most considerable. The first is the Illinois river; the second, though less considerable than the third, is taken by geographers as the continuance of the main stream of the Mississippi; and the third and greatest is the Missouri, regarded as a tributary of Mississippi.

The Illinois river ascends the state of that name in a north-easterly direction, and is navigable for a considerable distance to a point where it is connected by a canal with Lake Michigan at Chicago. By this means a continuous water-communication is established between New Orleans and the northern lakes, and by those lakes with the St. Lawrence.



VIII.—LAND AND WATER.

THE SURFACE OF THE EARTH,

OR FIRST NOTIONS OF GEOGRAPHY.

CHAPTER III.

141. Source of Mississippi.—142. Missouri and its tributaries.—143. The Amazons.—144. Its tributaries.—145. The Orinoco. — 146. The Rio de la Plata.—147. The river system of Europe.—148. General plan of the rivers of the world. CLIMATE.—149. Determines the animal and vegetable kingdoms.—150. Its dependence on latitude. — 151. Explained by the varying positions of the earth.—152. Spring equinox. — 153. Sun vertical at equator. — 154. Oblique at all other points.—155. Its thermal influence in different latitudes. — 156. Position of the earth on 21st June.— 157. Days longer than nights in northern hemisphere.—158. Temperature depends on sun's altitude and length of day. — 159. Thermal influence greatest on 21st June in northern hemisphere. —160. Position of the earth at autumnal equinox.—161. Why the longest day is not the hottest.—162. Why the summer is warmer than the spring.—163. The Dog-days.—164. Like phenomena in the southern hemisphere.—165. Position of the earth on 21st December. —166. Winter season explained.—167. Why the shortest day is not the coldest.—168. The Tropics.—169. The sun can only be vertical within them.—170. Illustration of the varying position of the earth in the successive months.—171. The arctic polar circles and the frigid zones.—172. Diurnal and nocturnal phenomena which characterise them.—173. The torrid zone.—174. Sun vertical twice a year in the torrid zone.—175. Temperate zone.

141. **Source of Mississippi.**—Ascending the main stream from its point of confluence with the Missouri, after passing several tributaries of less importance, we arrive at the falls of St. Anthony, which constitute the limit of its navigable course. Above these we find its source in a sheet of water, called Lake Istaca, situate near the northern limit of the territory of the United States, and at a short distance west of Lake Superior.

142. **Missouri and its tributaries.**—Returning to the confluence of the Mississippi with the Missouri, and ascending the latter stream, we find innumerable tributaries, variously denominated Smoky-hill-fork, Republican-fork, Platt-river, White-river, Yellow-stone-river, &c., until the stream, reduced to a number of diverging threads, loses itself in the flanks of the Rocky Mountains.

Such is a brief and rapid view of this prodigious vein of inland navigation. As shown in our general plan of the rivers, the total length of the Mississippi and its chief tributary is estimated at 4500 miles.

143. **The Amazons.**—Among the rivers of Southern America, which flow from the western declivities of the chain of the Andes, by far the most important is the Amazons, which, considered merely in its geographical character, ranks as the greatest of rivers. The total length from the mouth to the source of any one of its thousand tributaries, is less than the length of the Mississippi similarly measured, but numerous and large as the tributaries of the latter are, those of the Amazons are still greater in number, width, and depth.

This immense stream, and its countless affluents, drain a vast plain lying between the tableland of Brazil, on the south, and the chain of mountains rising from a similar tableland of less extent, on the north, called the tableland of Paramo. It receives tributaries accordingly from an extensive series of declivities completely surrounding it, from those of Brazil on the south, from the Andes of Peru on the south-west, from the Andes of Quito on the north-west, and from those of the mountain-chains of Paramo on the north.

The plain and surrounding declivities drained by this immense river system, is little less in extent than 3,000000 of square miles, being ten times the magnitude of the French empire. Its largest branch, considered as the commencement of the main stream, is called the Maranon, a name which is sometimes applied to the entire river. The main river and its tributaries are navigable at distances of nearly 2500 miles from its mouth, and its width, near its mouth, being nearly 100 miles, it resembles an arm of the sea more than a river.

144. **The tributaries** of this river are severally so considerable in magnitude and importance, that geographers are not agreed as to which of them should be regarded as the main stream, and the name Amazon is generally confined to the part of the river below the confluence of several chief tributaries, which unite nearly at the point where the Rio Negro or Black River joins the Amazons. A view of a good map of this part of Southern America, will give the reader a more clear idea of the course of this river and its tributaries, than could any mere verbal description. The greater tributaries are above twenty in number, all of which are navigable to a point near their sources, while the lesser ones are countless.

Notwithstanding the geographical superiority of the Amazons, and its vast extent of navigable water, it is inferior in commercial importance to the Mississippi; the districts of country traversed by the river and its branches consisting of tracts of natural forest, and uncleared and uninhabited ground.

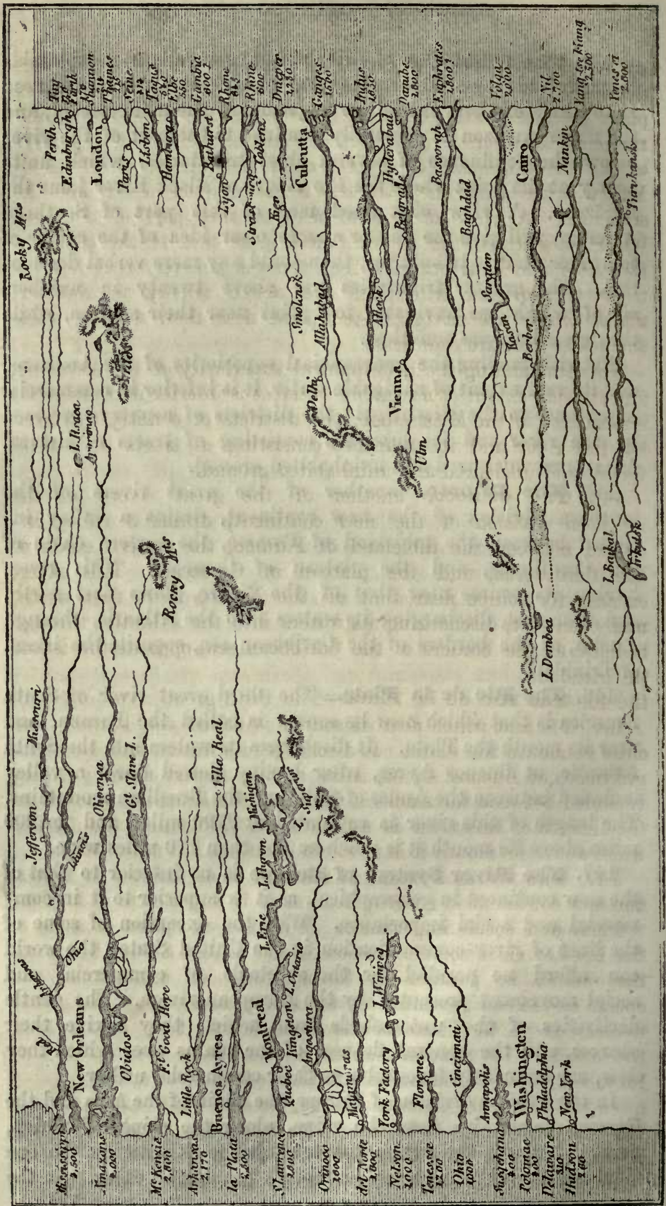
145. **The Orinoco,** another of the great rivers of the southern division of the new continent, drains a valley included between the tableland of Paramo, the eastern chain of the Cordilleras, and the plateau of Caraccas. This river, having its source near that of the Negro, flows first north, and then east, discharging its waters into the Atlantic, through a delta, at the borders of the Caribbean sea, opposite the island of Trinidad.

146. **The Rio de la Plata.**—The third great river of South America is that which near its source is called the Parana, and near its mouth the Plata. It discharges its waters into the South Atlantic, at Buenos Ayres, after having flowed down a valley included between the Andes of Chili and the Brazilian mountains. The length of this river is estimated at 2700 miles, and for 200 miles above its mouth it is nowhere less than 170 miles wide.

147. **The River System of Europe** is as inferior to that of the new continent in geographical, as it is superior to it in commercial and social importance. With the exception of some of the lines of river-communication in the United States, the world can afford no parallel for the spectacle of commercial and social movement presented by the European rivers. The gentle declivities of the water-sheds from which they derive their sources, and the general flatness of the plains over which they flow, are eminently favourable to their commercial utility.

In the western division of Europe, the chain of the Alps and the German mountains form the ridge, along the slopes of which, north and south, the waters flow towards the Atlantic on the one side, and the Mediterranean and Black Sea on the other. In the

Rivers of the Eastern Hemisphere.



Rivers of the Western Hemisphere.

eastern division there is no mountain-chain thus to divide the drainage. A slight and imperceptible elevation of the general plain produces two opposite water-sheds, commencing in a low range of hills separating the sources of the Dnieper from those of the Vistula, and winding along the plain to the tableland of Valdai, which forms its summit, 1200 feet above the level of the sea. The ridge then turns northward towards Lake Onega, and, following a winding course, terminates in the Ural Mountains, about 62° N. lat.

The drainage of the north side of this ridge forms the rivers which flow into the Baltic and the White Sea, that of its southern declivity those which flow into the Black Sea and the Caspian.

148. **General Plan of the Rivers of the World.**—The principal rivers of the world, with their tributaries, their embouchures, and their sources, are exhibited in one general plan on the opposite page, where their lengths are indicated.

CLIMATE.

149. Since the prevailing character of the animal and vegetable kingdoms, in each division of the earth's surface, depends chiefly on climate, it is necessary, on that account alone, independent of many other considerations, that the student in geography should be rendered familiar with the conditions, which in each part of the globe determine the varying vicissitudes and temperature of the seasons.

150. **Dependence of Climate on Latitude.**—The first and chief condition which determines the climate of a country, is its position with respect to the equator. It may be stated, subject to some special qualifications, that the nearer any country is to the Line, or what is the same, the lower its latitude, the higher will be the mean temperature of its seasons.

The reason of this is partly geographical and partly astronomical.

The earth revolves diurnally upon an axis, so directed that the equatorial parts are presented either exactly or nearly to the sun. They are presented exactly to that luminary at the epochs of the equinoxes, in March and September. From March to June they are gradually more inclined from the sun towards the south, the northern hemisphere inclining towards that luminary, so as to receive its rays more directly, and in greater quantity than the southern hemisphere. This inclination of the globe increases constantly from March to June, and then decreases from June to September. The northern hemisphere is thus more and more exposed to the light and warmth of the

sun, from March to June; the days during that interval are gradually longer and warmer. It is constantly less inclined from June to September; the days during that interval are gradually shorter and less warm.

Hence it is, that in the northern hemisphere the longest days and highest temperature take place after June, the temperature after March being more moderate. The interval between March and June constitutes, therefore, the spring, and the interval between June and September, when the accumulated effects of heat are greater, the summer.

151. This varying position of the earth towards the sun will be rendered more easily intelligible by illustrative diagrams.

Let N S in these four figures represent the axis of the earth, N being the north, and S the south pole. Let E Q at right angles to N S be the equator, and let S′ be the direction of the sun.

152. In fig. 8 is shown the position of the earth on the 21st of March, the day of the spring equinox. The equator E is then presented exactly in the direction of the sun, the light and heat of which are equally distributed between the two hemispheres.

Fig. 8.

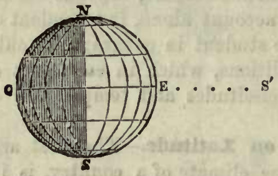
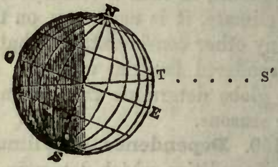
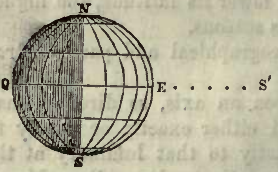


Fig. 9.



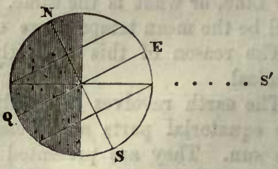
21st June.

Fig. 10.



21st September.

Fig. 11.



21st December.

The boundary of the enlightened hemisphere passes through the poles N and S, and divides into two equal parts all the parallels of latitude. As the earth revolves, therefore, upon its axis, each place upon its surface is during equal intervals exposed to and withdrawn from the sun's light. In other words, the days and nights are equal in all parts of the earth.

153. As the earth turns upon its axis N S, all the places upon the equator E Q are brought successively to the point E, directly under the sun. In other words, at all such places the sun is vertical daily at noon.

154. At all other parts of the earth between E and N, or between E and S, the sun is seen at noon obliquely, or what is the same, it is at a distance greater or less from the zenith. And the more distant the place is from the equator, the more distant will the sun be from the zenith at noon.

155. But since the thermal influence of the sun depends in a great degree upon its proximity to the zenith at noon, it follows that this influence will gradually decrease in going from E to N, or from E to S. The temperature, therefore, of the climate at the time of the equinox will gradually diminish as the latitude increases.

But since any two places at equal distances from the equator, north and south, would be presented towards the sun at noon with equal obliquities, it follows that so far as depends on this circumstance, the thermal influence of the sun at places having equal latitudes north and south, will be the same at the time of the equinoxes.

156. The position of the earth with relation to the sun on the 21st of June is shown in fig. 9. The equator E in the interval between the 21st of March and the 21st of June, has gradually declined to the south. The north pole N has consequently been turned more and more towards the sun S′, and the south pole S has been turned more and more from it. In this position, therefore, it is evident that the sun shines more fully on the northern, and less so on the southern hemisphere. The point T, to which it is vertical at noon, is now, not as in the former case upon the equator, but at the distance of $23\frac{1}{2}°$ north of it. Places in the northern hemisphere above this point are shone upon by the sun at noon with much less obliquity than places having equal latitudes in the southern hemisphere.

157. The circle which bounds the hemisphere of the earth enlightened by the sun, divides all the parallels of latitude unequally, the larger part of those in the northern hemisphere being enlightened, and the larger part of those in the southern hemisphere being dark.

It follows, therefore, that at this time the days are longer than the nights in the northern, and the nights longer than the days in the southern hemisphere.

158. Now the temperature of the seasons, in any given place, depends conjointly on the altitude to which the sun rises, and on the length of the day; for the greater the altitude is, the more

directly will the solar rays fall upon the place; and the longer the day is, the longer will be the interval during which the thermal influence of the sun is exerted, and the shorter will be the interval during which its presence will be withdrawn.

159. For all these reasons, therefore, on the 21st of June, when the northern hemisphere is most inclined towards the sun, and the southern most inclined from it, the thermal influence of the sun will be greater in the northern, and less in the southern hemisphere, than at any time from the 21st of March to the 21st of June.

During this interval the northern hemisphere is gradually more and more inclined towards the sun, and therefore the length of the day is continually increasing, as well as the altitude to which the sun rises at noon. These two circumstances combine in gradually increasing the thermal influence of the sun from the 21st of March to the 21st of June.

The same circumstances will show that during the same interval, the thermal influence of the sun in the southern hemisphere is gradually diminished; the days being there constantly shorter, and the altitude to which the sun rises at noon constantly less.

After the 21st of June the northern hemisphere is gradually less and less inclined towards the sun, and the southern less and less inclined from it, until at length on the 21st of September, the day of the autumnal equinox, the earth resumes the position, fig. 10, with relation to the sun which it had on the 21st of March, the equator E being then, as before, directed exactly towards the sun.

160. The two hemispheres therefore, as in March, being equally exposed to the sun, receive from it the same thermal influence, and the parallels of latitude being all bisected by the circle which bounds the enlightened hemisphere, the days and nights are equal at all parts of the earth.

Since the altitude to which the sun rises, and the length of the days at equal intervals before and after the 21st of June, are the same, and therefore the thermal influence of the sun also the same, it might be inferred that the temperature of the weather would likewise be the same; and if this inference were just, it would follow that the season from the 21st of March to the 21st of June, would be similar in all its thermal characters to the season from the 21st of June to the 21st of September, except that the succession of temperatures would be developed in a contrary order. Thus it would be expected that the temperature of the weather ten or twenty days after the 21st of June would be identical with its temperature ten or twenty days before the 21st of June.

161. But it is notorious that the thermal phenomena are not at all in accordance with this; the season from the 21st of March to the

21st of June, called the Spring, having generally a much lower temperature than the season from the 21st of June to the 21st of September, called the Summer.

Let us see, then, whether we cannot render evident the cause of this.

The temperature of the weather in a given place, depends not exclusively upon the thermal influence exercised by the sun during each day. It must be remembered that when the days are much longer than the nights, and the sun rises to a considerable altitude, a greater quantity of heat is imparted to the atmosphere and to all objects upon the surface during the day, than is lost during the night, and, consequently, an *increment* of heat is given to all such objects every twenty-four hours. The consequence is, that the general effect of the sun's thermal influence during each successive twenty-four hours is to augment the temperature, and thus to increase by accumulation the heat from day to day; and this daily increase will obviously continue until, by the shortening of the days and the decrease of the sun's altitude, the increment of heat during the day becomes equal to its decrement during the night. The day on which that takes place will be the hottest day, because it will be that upon which the daily accumulation will cease. After this, the days being further shortened, and the sun's altitude further diminished, the increment of heat during the day will be less than its decrement during the night, and after each interval of twenty-four hours there will be on the whole a decrease of heat, and so the temperature of the weather will be diminished.

162. Now, from a due consideration of these circumstances, it will be easy to see why the season of summer is warmer than the season of spring, although the sun's altitude and the length of the days are, on the whole, precisely the same both in one season and the other, only succeeding each other in a contrary order. Until the 21st of June the daily thermal influence of the sun continually increases, for the reasons just explained, and it is greater on the 21st of June than on any other day before or after. But although this thermal influence decreases after the 21st of June it is still considerable, and from day to day adds something more or less to the heat already accumulated in the atmosphere, and consequently continues to augment the temperature; and this increase only ceases, when the thermal action of the sun during the day, begins to be counteracted and balanced by the loss of heat during the night.

163. Hence it arises that a certain interval, from the 21st of June to the latter part of July, is generally the hottest part of the summer, being called the *Dog-days*, either because of the

prevalence of canine madness during that period, or because at an early epoch in astronomical history the Dog-star rose before the sun in the morning at that season, and thus harbingered the God of Day. It may even have happened that the Dog-star took its name originally, from the prevalence of canine madness at that season.

164. The circumstances which explain the phenomena of summer in the northern hemisphere, will also explain those of winter during the same interval in the southern hemisphere, since the southern hemisphere at all times is inclined from the sun, exactly as much as the northern hemisphere is inclined towards it, as will be apparent by reference to fig. 9.

165. After the 21st of September (fig. 10), the day of the autumnal equinox, the equator is gradually inclined towards the north, and the northern hemisphere gradually inclined from the sun, and this inclination constantly increases until the 21st of December, when it is greatest, as shown in fig. 11.

The solar rays, as will be apparent from the figure, then fall with greatest obliquity on the northern hemisphere, and with least obliquity on the southern. The parallels of latitude are unequally divided, in both hemispheres, by the circle which bounds the enlightened part of the earth. In the northern hemisphere the greater portions of these parallels are dark, and the lesser portions enlightened, while the contrary takes place in the southern hemisphere. The days are, therefore, shorter than the nights in the northern, and longer in the southern hemisphere; and the sun rises only to low altitudes in the former, but to considerable altitudes in the latter. In fine, all the circumstances show that, in this position of the earth, the summer commences in the southern, and the winter in the northern hemisphere.

166. After the 21st of December, the inclination of the northern hemisphere from the sun gradually and constantly diminishes until the 21st of March, when the equator is once more presented directly to the sun, which affects both hemispheres alike.

Since the 21st of December is the shortest day, and that upon which the sun rises to the least altitude, it is consequently that on which its thermal influence is least, and it might therefore be expected to be the coldest day, and consequently to be mid-winter. It is notorious, on the contrary, that the coldest weather is at a later period. This is explained upon the same principles exactly, as those which show why the 21st of June is not the hottest day.

167. The decrement of heat which takes place in the atmosphere owing to the length of the night, the shortness of the day, and the low altitude of the sun on the 21st of December, is greater

than the decrement on any succeeding day; but still on these succeeding days there is still a decrement of heat, though a less one, and therefore on the whole the temperature must continue to fall, and it will so continue until by the increasing length of the day, and the decreasing length of the night, and the increasing altitude of the sun, the increment of heat during the day becomes equal to its decrement during the night; after that takes place, the result of the sun's influence during each twenty-four hours will be on the whole an increase of heat, and the temperature of the weather will accordingly be augmented.

Hence it is that the winter season in the northern hemisphere is the interval between the 21st of December and the spring equinox; the same interval being the summer season in the southern hemisphere.

The altitude to which the sun rises at noon constantly increases until the 21st of June, when it becomes as it were stationary, and afterwards decreases. In the same manner the altitude at noon constantly decreases until the 21st of December, after which it increases, having remained in like manner stationary for a certain interval. These two epochs have therefore been called the solstices, one being denominated the summer, and the other the winter solstice, from a Latin word which signifies the standing or stationary position of the sun.

168. When the northern hemisphere is most inclined towards the sun, as shown in fig. 9, the sun is vertical at noon to all places at $23\frac{1}{2}°$ north of the equator. Before that day, and after it, the sun's altitude at noon is less than 90°, and consequently it does not reach the zenith. It may be considered therefore gradually to approach the zenith at such places until the 21st of June, and then gradually to recede from it.

From this circumstance the parallel of latitude which passes through such places has been called the *tropic*.

Similar phenomena are produced at the corresponding parallel of south latitude, and these parallels are accordingly called respectively, the northern and southern tropic, or the *Tropic of Cancer* and the *Tropic of Capricorn*.

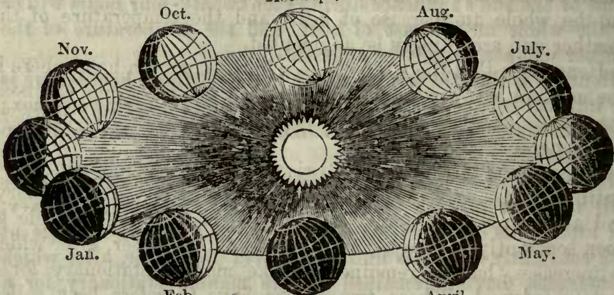
169. It will be evident, by considering the diagrams, fig. 9 and fig. 11, that the sun can never be vertical at noon to any part of the earth except to places which lie between the tropics, and at all such places it is vertical at noon twice in the year.

170. These astronomical causes of the vicissitudes of the seasons may be further illustrated by the diagram, fig. 12, which presents a perspective view of the earth in twelve successive positions which it assumes in one revolution round the sun, the observer being supposed to view it from the north side of the plane of its

orbit. Its motion in that case is in a direction contrary to that of the hands of a clock, or to that of a common screw when turned so as to cause it to move inwards or forwards.

While the globe thus moves round the sun, its axis keeps constantly the same direction, so that in any one position it is

Fig. 12.



parallel to the direction which it had in any other position. On the 21st of June, as shown to the right of the diagram, the northern extremity of the axis, or the north pole, leans towards the sun through an angle of $23\frac{1}{2}°$. If we suppose a parallel of latitude to be described at that distance from the pole, all places within that parallel will receive the light of the sun, and the rotation of the globe on its axis will not throw any of these places upon the dark side of the earth. It follows, therefore, that on the 21st of June the sun does not set at all to any place above that parallel, and there is consequently twenty-four hours day.

By referring to the position of the earth, on the extreme left of the figure, which it has on the 21st of December, it will be seen that then the north pole is inclined from the sun, just as much as it was inclined towards it on the 21st of June, and that the same places, bounded by the parallel of latitude $23\frac{1}{2}°$ from the pole, which on the 21st of June lay altogether on the enlightened side of the globe, and enjoyed twenty-four hours day, now lie on the dark side, and have twenty-four hours night. As the sun never sets to such places on the 21st of June, so it never rises to them on the 21st of December.

In the positions successively assumed by the earth, in July and August, the north pole is less and less inclined towards the sun, and the part around it, which has no sunset, is limited by a less and less parallel of latitude. On the 21st of September, the equator being presented to the sun, there is no part around the pole

which has continual day, all places being twelve hours exposed to the sun, and twelve hours removed from it.

After the 21st of September, the north pole begins to incline from the sun, and in October, a small portion around it is entirely deprived of the sun's light. This portion, thus involved in continual night, constantly increases in extent until the 21st of December, when it extends to the parallel of latitude already mentioned. After the 21st of December, the north pole is less and less inclined from the sun, so that the portion involved in continual night is less in January, and still less in February, and on the 21st of March, as on the 21st of September, there are twelve hours day and twelve hours night to all places.

After the 21st of March, the north pole begins again to lean towards the sun, and a portion of the earth around it enjoys continual day, this portion increasing in extent during the months of April and May, and attaining its greatest magnitude on the 21st of June, when its extent, as already explained, is a circle $23\frac{1}{2}°$ from the pole.

171. The parallel which is $23\frac{1}{2}°$ from the pole, is $66\frac{1}{2}°$ from the equator, and consequently has the latitude north of $66\frac{1}{2}°$.

This parallel of latitude is called the *Arctic* or *Polar Circle*, and the polar region included by it is called the *Frigid Zone.*

All the circumstances, which are here explained, respecting the north polar region, circumscribed by the arctic circle, will be equally applicable to the corresponding region, circumscribed by a circle $23\frac{1}{2}°$ from the south pole. Such a circle is called the *South Polar* or *Antarctic Circle*, and the polar region circumscribed by it is the *Southern Frigid Zone.*

172. Although the diurnal and nocturnal phenomena of the two frigid zones, northern and southern, are precisely the same, they are not simultaneous, those which are identical being produced at opposite epochs of the year, as will be rendered evident by examining attentively the several positions of the illuminated and dark hemispheres of the globe in the successive months, in fig. 12. When the entire north polar circle is enlightened on the 21st of June, the entire south polar circle is dark. There is continual day in the one, and continual night in the other. On the contrary, when the entire north polar circle is dark on the 21st of December, the entire south polar circle is enlightened. There is continual night in the one, and continual day in the other.

The phenomena on the 21st of June, therefore, in the northern frigid zone, are identical with those of the 21st of December in the southern frigid zone, and *vice versâ.*

In the like manner, there is just so much of the northern polar region enlightened, and of the southern polar region darkened, in July, as there is of the northern polar region darkened, and the southern enlightened, in January. The diurnal and nocturnal vicissitudes, therefore, of the northern frigid zone in July, are identical with those of the southern frigid zone in January, and *vice versâ*.

If the reader will take the trouble of following the position of the earth from month to month, as shown in fig. 12, he will be able to satisfy himself, that at all intervals of six months the vicissitudes of light and darkness are in the same way reciprocated between the two frigid zones.

It might be inferred, that the continual presence of the sun above the horizon, would necessarily produce a great calorific effect; and at least during that portion of the year, during which they are respectively inclined towards the sun, the polar circles would enjoy intense heat. That such, however, is not the case is easily explained. The heat imparted by the sun to any part of the earth exposed to its influence, depends, as already stated, on two conditions: first, the altitude to which it rises, and secondly, its continuance above the horizon, or the length of the day. But the former condition has a vastly greater influence upon the thermal effects than the latter. Although, therefore, the continuance of the sun above the horizon, at the polar circles, is favourable to the development of heat, yet the very low altitude to which it rises counteracts this effect; so that within the polar circles, even with the influence produced by the continuous presence of the sun, the general temperature is invariably below that at which water freezes.

It is from this continuance of a temperature so low that the frigid zone has taken its name.

173. **Torrid Zone.**—The part of the earth included between the tropical circles, which comprises all places having a latitude less than 23½°, is called the *Torrid Zone*.

Although the exposure of these regions to the heat of the sun varies within certain limits between December and June, being most completely presented to that luminary in March and September, they, nevertheless, receive the solar influence in a much more powerful degree, than the parts of the globe having higher latitudes in the one hemisphere and the other.

It is demonstrated in physics, that the heating power of the sun's rays falling upon any object increases in proportion as they approach to the perpendicular direction upon it. At the time of the equinoxes, therefore, the noon-day sun upon the Line, project-

ing its rays perpendicularly downwards, produces the greatest possible calorific effect.

At these times, also, the sun, rising precisely in the east, ascends the heavens at right angles to the horizon, until at noon it reaches the zenith; after which it descends perpendicularly in like manner, and sets precisely in the west.

174. **Sun vertical twice a year in the Torrid Zone.**—Every point of the torrid zone is presented, at one period or another of the year, directly to the sun, so that there are two days in the year upon which the sun at noon is vertical at such places, and its extreme departure from the zenith at noon is always very limited. Thus to places on the Line, the sun at noon never departs from the zenith more than $23\frac{1}{2}°$, and even at the limits of the torrid zone, that is, at the latitude $23\frac{1}{2}°$ north or south, the sun which on the 21st of June is vertical at noon in the northern, and on the 21st December in the southern hemisphere, is not more than 47° from the zenith at noon on the 21st of December in the northern, and on the 21st of June in the southern hemisphere; for all places within the tropics the extreme distance of the sun from the zenith at noon must always be less than 47°.

Indeed it may be stated generally, that for places between the tropics, the greatest distance of the sun at noon from the zenith will be found by adding $23\frac{1}{2}°$ to the latitude of the place, and that twice in the year it passes through the zenith at noon.

When it is considered that the temperature of the weather mainly depends on the distance of the sun from the zenith at noon, increasing as that distance decreases, it will be easily understood why the climate of the torrid zone is characterised by that extremely elevated temperature from which it takes its name; for although the sun at noon, during a certain part of the year, is at a distance more or less considerable from the zenith, the interval during which it has this distance is comparatively short, and that during which it is in or near the zenith much more considerable.

The hottest seasons occur, not as might be first supposed, upon the Line, but at and within a limited number of degrees of the tropics; because at such latitudes the sun at midsummer continues to cross the meridian very near to the zenith for a much more considerable time than on the Line at the epochs of the equinoxes, where its change of declination is much more rapid.

175. **Temperate Zone.**—The parts of the globe included between the limits of the torrid and frigid zones,—that is between the latitudes $23\frac{1}{2}°$ and $66\frac{1}{2}°$,—is exempt from the extremes of temperature which characterise the one and the other of these regions. Within its limits the sun never ascends to the zenith, nor on the other hand are the phenomena of continuous day or

continuous night ever witnessed. The warmth of summer is produced by long days, combined with moderate meridian altitudes, and the rigour of winter is mitigated by the presence of the sun above the horizon for a considerable interval, even on the shortest days.

It must not be understood, that within the limits of what is thus called the temperate zone, the climates are uniformly the same. On the contrary, in approaching those limits, at which it is united with the torrid and the frigid zones, the character of the climates approach gradually to those peculiar to the one extreme zone and the other, so that the climates of the higher latitudes of the temperate zone differs but little from those of the lower latitudes of the frigid zone, while those of the lower latitudes of the temperate zone, approximate gradually and insensibly to those of the higher latitudes of the torrid zone. In fact, within the limits of the temperate zone are included a much greater variety of climates than any which characterise either of the extreme zones.

VI.—TURKEY—GREECE.

THE SURFACE OF THE EARTH,

OR FIRST NOTIONS OF GEOGRAPHY.

CHAPTER IV.

176. Climate, dependent on elevation.—177. Vegetation of the Himalayas.—178. Vegetation of the Andes.—179. Animals of the tropics.—180. The Himalayas—Animals inhabiting them—181. The local character of climate.—182. Heat received from celestial spaces.—183. Why the temperature of the earth is not indefinitely increased.—184. Effect of clouds.—185. Effect of contact of air and earth.—186. Thermal effects of a uniform surface.—187. Why this regularity does not prevail. Mountains.—188. Maps and globes in relief.—189. Johnston's Physical Maps.—190. Mountain ranges not uniform.—191. Spurs.—192. Relief of the earth's surface.—193. Effect of the contemplation of mountain scenery.—194. The Pyrenees.—195. The Alps.—196. Average height of continents.—197. New mountain ranges possible. The Ocean.—198. Greatest depth.—199. Uses of the ocean.—200. General system of evaporation and condensation.—201. Climatic effects.—202. Ocean currents.—203. Antarctic drift current.—204. Its equatorial course.—205. Gulf stream.—206. Course and limits of ocean currents evident.—207. Ocean rich in animal life.—208. Moral impressions.

176. Climate dependent on elevation. Snow Line.—It has been explained in our Tract on Terrestrial Heat, that as we ascend into the atmosphere from the level of the sea, the mean temperature gradually decreases, and beyond a certain elevation it falls even below the freezing point of water; above this limit, therefore water cannot exist in the liquid state, and must assume the state of snow or ice. Such an elevation is accordingly designated the limit of perpetual snow, and it is marked on all lofty mountains by the limits of their snow-covered sides. This boundary is accordingly called the *Snow Line.*

It may be stated as a general fact, subject nevertheless to some local qualification, that the elevation of the snow-line is greatest at those parts of the earth, where the climate at the level of the sea is hottest, and that its elevation decreases with the decrease of the mean temperature of the same level. The snow-line, therefore, has the greatest elevation within the tropics, and decreases gradually with the increase of latitude, until at the polar circles it falls to the surface.

Since climate therefore varies, not only with the latitude but with the elevation of the place above the level of the sea, it follows that in mountainous regions a variety of climates will prevail, depending on the elevation of the summits. If that elevation exceed the limits of the snow-line, all varieties of climate between that which characterises the sea level, or which is natural to the plateaux on which the mountains stand, and the climate of the poles are found, and consequently a corresponding variety of natural productions, vegetable and animal, and corresponding susceptibilities of culture prevail. This is a circumstance which gives much interest to mountainous countries, and often confers upon them great commercial and social advantages.

It is evident, also, that the higher the mean temperature of the plateaux is upon which snow-capped mountain ranges stand, the greater will be the varieties of climates exhibited between their summits and their bases, and the greater consequently will be also the variety of natural productions and artificial culture. Hence arises the magnificent display of vegetation exhibited in those ranges of the Andes and Cordilleras, and other lofty ridges which intersect the torrid zone.

177. Vegetation of the Himalayas.—Although the chain of the Himalayas far exceeds in elevation the Andes and Cordilleras of South America, they are thus, from their geographical position, being situate far beyond the limits of the torrid zone, excluded from the advantages here noticed, and they present none of that inexhaustible variety of phenomena by which the ridges

which rise to such vast altitudes from the plateaux of the torrid zone are characterised. Beautiful as are the valleys of Kumaoon and Nepaul, they are not signalised by the presence of a single palm-tree. On the southern slope of the Paropamisan range, which extends over 350 miles of Persia and Afghanistan, and separates the deserts of Yezd and Turkestan, Nature nowhere displays that profusion of arborescent grasses, tree-ferns, heliconias, and orchideæ which are witnessed on the higher plateaux of the tropical mountains. On the slopes of the Himalayas, under the shade of the deodar and the large-leaved oak peculiar to these Indian alps, the rocks of granite and mica-schist are clothed with forms closely resembling those which characterise Europe and northern Asia. The species indeed are not identical, but they are similar in their aspect and physiognomy, including junipers, Alpine birches, gentians, parnassias, and prickly species of ribes. The chain of the Himalayas is also wanting in those imposing volcanic phenomena, which in the Andes and the Indian Archipelago often recall to the inhabitants, in characters of terror, the existence of forces developed within the globe. Moreover, on the southern declivity of the Himalayas, where the vapour-loaded atmosphere of Hindostan deposits its moisture, the region of perpetual snow descends to a zone the elevation of which does not exceed 13000 feet. Thus the region of organic life ceases at a limit 3000 feet lower, than that to which it extends in the equinoctial portion of the Cordilleras.

178. **Vegetation of the Andes.**—The mountainous regions of the Tropics present a further advantage in being that part of the globe, as already mentioned, where the greatest possible variety of impressions are produced by the contemplation of nature. In the Andes of Cundinamarca, Quito, and Peru, furrowed by deep barrancas, it is given to man to behold at once all the plants of the earth, and all the stars of the firmament. There, at a single glance, the beholder sees lofty feathered palms, humid forests of bamboos, and all the beautiful family of musaceæ, and, above these tropic forms, oaks, meddlars, wild roses, and umbelliferous plants, as in our European homes. There, too, both the celestial hemispheres are open to his view, and when night arrives, he sees displayed together the constellation of the Southern Cross, the Magellanic clouds, and the guiding stars of the Bear, which circle round the Arctic Pole. There the different climates of the earth, and the vegetable forms of which they determine the succession, are placed one over the other, stage above stage, and the laws of the decrement of heat are indelibly written, on the rocky walls and rapid slopes of the Cordilleras, in characters easily legible to the intelligent observer.

Not only is the torrid zone by the abundance and luxuriance of its organic forms most rich in powerful impressions, but it presents another and greater advantage, in the uniform regularity which characterises the succession of its meteorological and organic changes. The well marked lines of elevation which separate the different forms of vegetable life, demonstrate in a striking manner the same play of general and invariable laws, which govern the celestial motions reflected in terrestrial phenomena. Thus, in the burning plains which stretch nearly on the level of the sea in these regions, we behold in profusion the families of bananas, of cycadaceæ, and of palms, of which the number of species included in the Floras * of the tropical regions, has been so wonderfully augmented by modern botanic travellers. To these succeed, on the slopes of the Cordilleras, in the mountain valleys, and in humid and shaded clefts of the rocks, tree-ferns raising their thick cylindrical stems, and expanding their delicate foliage, whose lace-like indentations are seen projected against the deep azure of the firmament. There, too, flourishes the cinchona, whose fever-healing bark is deemed the more salutary, the oftener the trees are bathed and refreshed by the light mists, which form the upper surface of the lowest stratum of clouds.

Immediately above the region of the forests the ground is covered with white bands of flowering social plants, small aralias, thibaudias, and myrtle-leaved andromedas. The alp-rose of the Andes, the magnificent befaria, forms a purple girdle round the spiry peaks. On reaching the cold and stormy regions of the Paramos, shrubs and herbaceous plants, bearing large and richly-coloured blossoms, gradually disappear, and are succeeded by a uniform mantle of monocotyledonous plants. This is the grassy zone, where vast savannahs clothe the high tablelands and the wide slopes of the Cordilleras, whence they reflect a yellow hue,—savannahs, on which graze llamas and cattle descended from those formerly brought from the Old World. Trachytic rocks next appear forcing the turf and rising high into those strata of the atmosphere containing a less proportion of carbonic acid, and supporting only plants of inferior organisation, such as the lichens, the lecideas, and the many-coloured dust of the lepreria, which forms small round patches on the surface of the stone.

Scattered patches of fresh fallen snow arrest the last feeble traces of vegetation, and are succeeded by the region of perpetual snow, of which the lower limit is distinctly marked, and undergoes but little change.

* The collection of vegetable productions natural to a country is called its *flora*, and that of the animals indigenous to it its *fauna*.

The elastic subterranean forces strive, for the most part in vain, to break through the snow-clad domes which crown the ridges of the Cordilleras, but even where these forces have actually opened a permanent channel of communication with the outer air, either through crevices or circular craters, they rarely send forth currents of lava, erupting more frequently ignited scoriæ, jets of carbonic acid gas, sulphuretted hydrogen, and steam.*

179. **Animals of the tropics.**—A corresponding variety is found in the animal kingdom in these regions at the level of the sea; upon the plains which extend over the tropical regions are found the varieties of monkeys, crocodiles, the boa-constrictor, rattle-snake, jaguars, and macaws. Higher up, at a level rising from 5000 to 10000 feet, at the base of the Andes, are found the ocelot, the strutheo rea, and the duck. Higher still, the ape, the puma, and the llama, and, in fine, about the snow-line, hawks, vultures, bears, and the condor, which rises upon its vast wings above the lofty summits of Chimborazo and Aconcagua.

180. **The Himalayas** are characterised, also, by animals dwelling in a succession of stages one above the other. Thus, upon the plains are found the tiger, the peacock, and the Bactrian camel. Higher up the bat, the Cashmere goat, and the pheasant, and just below the snow-line, the sheep, the yak, the pigeon, the robin, &c.

181. **The local character of a climate** depends on the mean temperature of the atmosphere and of the surface of the earth. And this temperature itself must depend chiefly on the heat imparted to the atmosphere and the earth by the sun. The solar rays, in passing through the atmosphere to the earth, impart to that very attenuated and transparent fluid an inconsiderable quantity of heat, their chief thermal power being exerted on the surface of the earth, which forms the base of the atmospheric ocean. The earth, like all bodies, absorbs a certain proportion of the heat thus transmitted to it, and what it fails to absorb it reflects exactly as a surface would reflect light. The heat which it reflects, not entering it, does not affect its temperature, and it is warmed exclusively by the portion it absorbs. This portion is so considerable, that if it were uniformly diffused over the entire surface of the earth, it would be sufficient to dissolve annually a shell of ice 100 feet thick covering the entire globe.

182. **Heat received from celestial spaces.**—But besides the heat received from the sun, the earth also receives a considerable portion of heat from the surrounding firmament, in other words,

* Humboldt's Cosmos. Introduction.

from the countless myriads of suns composing the stellar universe which are seen nightly sparkling in the heavens; and this latter source of heat differs from that of the sun, inasmuch as all parts of the earth are constantly exposed to it night and day, whereas they are only exposed to the direct influence of the sun during average intervals of twelve hours.

It has resulted from the experiments and observations of M. Pouillet, that the quantity of heat thus received by the earth from the celestial spaces is such, that if it were uniformly diffused over the surface it would be sufficient to melt a shell of ice, enveloping the earth, 85 feet thick.*

183. **Why temperature of the earth is not indefinitely increased.**—It may be asked, therefore, how it happens that if the earth receive and absorb an annual quantity of heat so enormous, its temperature is not raised to such a point as to be incompatible with the continued existence of the organised world upon it. It might be expected that the heat absorbed in the torrid zone, being transmitted by the process of conduction through the solid matter composing the earth to the colder regions of the poles, would first dissolve all the ice there collected, and then gradually raise the temperature of the polar regions, to which the animal world would first take refuge flying from the scorching region of the tropics, and which would become at the same time the theatre of the present flora of the temperate and tropical zones, and later would be raised to a temperature destructive of all organisation.

Such a catastrophe is prevented, and the thermal condition of the globe maintained within the necessary limits, by a remarkable property with which matter has been endowed by its Maker, in virtue of which all bodies possess the quality of thermal radiation, in the exact proportion in which they are endowed with that of thermal absorption. The heat, therefore, which every part of the surface of the earth absorbs from the solar rays, it throws back by the process of superficial radiation, and if the atmosphere were everywhere cloudless, the heat thus radiated back would pass into the celestial spaces, and the atmosphere would then, in spite of the solar rays passing through it, remain at a very low temperature.

184. **Effect of clouds.**—The existence of clouds, however, modifies this. The heat radiated from the surface of the earth is in a great degree intercepted, and prevented from escaping into the celestial regions, by the clouds, which reflect and radiate it back again to the earth through the lower strata of the atmosphere; and thus these thermal rays, being reverberated between the

* See Tract on Terrestrial Heat, Museum, vol. 3, p. 65.

clouds and the surface, warm the lower strata of the atmosphere through which they are so frequently transmitted.

185. **Effect of contact of air and earth.**—But the atmosphere also receives heat from the earth, by the contact of its lowest strata with those parts of the terrestrial surface, which have a higher temperature. When these lowest strata are thus warmed by contact, they ascend as heated air does in a chimney, air having a lower temperature flowing in to take their place.

It is by these several means therefore, much more than by the direct influence of the sun, that the temperature of the atmosphere is maintained and regulated.

186. **Thermal effects of an uniform surface.**—If the whole surface of the earth consisted of one homogeneous material, whether solid or fluid, and were in one uniform condition, its powers of reflection and absorption, and consequently its power of radiation, would be everywhere the same. In that case the thermal influence of the sun, governed by no other conditions than those of its altitude and continuance above the horizon, would necessarily be the same at all points of the same parallel of latitude, since, at all such points, the sun's altitude and the length of the day are necessarily the same. The equator and each parallel of latitude would then be isothermal lines, a word which expresses a line upon the surface of the earth, all points of which have the same mean temperature. Not only would the mean temperatures of all points on the same parallel be the same, but the extreme temperatures of summer and winter would likewise be the same. In other words, all places having the same latitude would, under the conditions supposed, have identically the same climate. They would have the same average annual temperature, and would be subject to the same vicissitudes of seasons.

In comparing parallel with parallel, the average annual temperature, as well as the extremes of the seasons, would regularly increase with the latitude.

187. **Why this regularity does not prevail.**—But the conditions which would produce such climatic phenomena do not exist on the terrestrial surface. Instead of consisting of one uniform material, that surface is diversified,—first, by land and water; and secondly, the land itself is still more diversified in its character, according as it is more or less clothed with vegetation, and even where it is destitute of vegetation, it varies according to the quality of the rocks or other strata which compose its uncovered surface. The reflecting, absorbing, and therefore radiating powers of the land, are infinitely diversified. In general the foliage of vegetation is a powerful radiator, while the naked

soil, or rocks, are comparatively feeble radiators and stronger reflectors. The water of the ocean, which covers three-quarters of the terrestrial surface, is much more uniform in its thermal properties than the land. But even those properties of the ocean are modified by the congelation which takes place on so vast a scale in the frigid zone.

All these circumstances combined, and many others which can only be fully understood by a more profound study of physical geography, render the actual climatic phenomena extremely different from those which would depend on the latitude alone, and which would be developed on a globe the superficial materials of which would be uniform.

The departure of the lines of equal, mean, and extreme temperatures from the parallels of latitude, has been already explained in our Tract upon Terrestrial Heat, and it will not, therefore, be necessary to insist further upon them here.

VII.—INDIA.

MOUNTAINS.

188. **Maps, and Globes in Relief.**—Elementary instruction in geography has been hitherto for the most part limited to the description of the outlines of land and water. The varieties of form depending on relief have been comparatively neglected. This has arisen most probably from the difficulty of presenting to the student visible representations of such forms. Maps and globes, showing in moulded relief the inequalities of the land, have indeed been constructed, and with suitable explanations may be found useful to the teacher and the pupil. Independently, however, of their cost, which is necessarily considerable, they are subject to grave objection, owing to the enormous violation of proportion between the vertical and the horizontal dimensions, which they must necessarily exhibit. It has been explained elsewhere, that the elevation of the most lofty mountain-summits does not exceed the 1600th part of the Earth's diameter, and consequently such a summit, if formed in relief in its just proportion on a 16-inch globe, would be represented by a protuberance not exceeding the hundredth part of an inch. All maps and globes, therefore, presenting the inequalities of the land in moulded relief, must, in order to render them perceptible at all, give the vertical magnitude exorbitantly disproportionate to the horizontal dimensions. When such illustrations are used for the purpose of elementary instruction, the teacher should be careful to impress upon the mind of the pupil this inevitable departure from the natural proportions.

189. **Johnston's Physical Maps.**—The expedient adopted in the physical maps of Mr. A. K. Johnston renders them exempt from this objection, although the same vivid illustration of the superficial inequalities is not presented by them. In these the plains, valleys, and lowlands are coloured green, the elevated plateaux and table-lands brown; and the mountain-ridges and peaks are distinguished by obvious marks indicative of their relative altitudes, the actual heights being marked in numbers of English feet. The sea is also everywhere distinguished from the land by its blue colour. As a physical illustration, these maps are therefore, as I conceive, as perfect as the nature of the subject of instruction allows.

190. **Mountain-ranges not uniform.**—Although each of the great continental systems, which have been already described, is characterised by a certain prevailing direction, it must not be supposed that it follows one uniform and unbroken course, or even that it consists of a single uninterrupted series. They are, on

the contrary, liable to frequent changes of direction, are in many places discontinuous, and are subject to still greater irregularity in both height and width.

191. **Spurs.**—Each main ridge also throws out lateral ramifications at various angles with its general direction, called *spurs.* Those are often themselves considerable chains of mountains, throwing off secondary spurs parallel to the primary chain, or nearly so. These subordinate ranges, intersecting each other at various angles, and broken by valleys and ravines, form a reticulation, which usually covers a vast extent of country stretching out at either side from the base of the principal chain. They decrease gradually in their dimensions, both horizontal and vertical, with their distance from the parent chain. Every one who has visited the country on either side of the ranges of the Alps, the Pyrenees, or Mount Atlas, will be familiar with these features.

192. **Relief of the Earth's surface.**—Considering the Earth as a globe formed of solid matter, subject to superficial inequalities, and partially covered with water, the land must be regarded merely as the more elevated parts rising out of the waters, which, according to the common law of gravitation, are lodged upon the lowest levels. The level parts of the land must be considered as plateaux, table-lands, or terraces formed upon vast mountains, the bases of which are at the bottom of the Ocean.

The mountains, in like manner, which rise from the surface of the land, must be considered as only the highest peaks of those whose bases are established upon the bottom of the deep, and the plains around them, upon which they rest, as merely terraces or plateaux forming steps, as it were, in ascending their acclivities.

In accordance with these views, it is found that systems of mountains, whether they form continued chains, detached groups, or isolated peaks, seldom have their bases upon a low level. On the contrary, the plains upon which they stand are almost always plateaux or tablelands at a considerable altitude above the level of the sea. The heights of mountain-summits being always expressed with relation to the level of the sea, it must therefore be remembered, that in estimating heights above the general level of the plains on which the mountains stand, it is necessary to deduct the heights of such plains from the tabulated heights of the mountains.

That this correction is of importance, will be comprehended when it is remembered, that the heights of the tablelands upon which the great chains of mountains stand, above the level of the sea, varies from 2000 to 12000 feet. Thus, for example, the tabulated altitude of Kunchinjunga, the highest peak of the Himalayas, and indeed the most lofty point hitherto discovered

on the globe, is 28178 feet; but the tableland of Thibet, on which it stands, has an altitude of about 11000 feet, so that the height of the peak above the level of the surrounding plain is only 17000 feet.

In like manner, the height of Mont Blanc is 15739 feet, but the height of the Lake of Geneva being 1450 feet, and the base of Mont Blanc being several hundred feet more, it follows that the summit of Mont Blanc cannot be much more than 13000 feet above the level of its base.

From the two examples here given, it will be apparent how little relation the tabulated heights of mountains sometimes have, to the appearance which they would present to an observer. The highest peak of the Himalayas, measured from the level of the sea, is nearly double that of Mont Blanc, and is sometimes therefore described as being a mountain, such as would be produced by piling two like Mont Blanc one upon the other. Such an illustration, nevertheless, is most inappropriate, as appears from what has been just stated, since an observer of Kunchinjunga must necessarily view it from a station about 11000 feet above the level of the sea, while an observer of Mont Blanc can view it from a station less than 2000 feet above that level. Mont Blanc would, therefore, under these circumstances, have nearly as great an apparent height as Kunchinjunga.

193. **Effect of the contemplation of mountain scenery.**—The more the imagination and understanding are impressed with the lofty and massive mountain ranges—as evidences of great terrestrial revolutions which the globe has undergone at distant epochs of its history—as the limits of varying climates—as the lines of separation forming the watersheds of opposite regions—and in fine, as the theatres of peculiar vegetation—the more necessary is it to obtain a correct numerical estimate of their actual volume, so as to demonstrate the comparative minuteness of their mass beside that of the extensive platforms on which they stand.

194. **The Pyrenees.**—Take, for example, the chain of the Pyrenees, the area of whose base and whose mean elevation have been determined with great precision. Let us suppose that this entire mountain mass were spread equally over the whole surface of France, and let it be required to determine what would be the thickness of the stratum which it would then form. Nothing can be more simple than such an arithmetical problem, and the result of its solution is, that the whole surface of France would be raised only 115 feet.

195. **The Alps.**—In like manner, if the chain of the Alps were levelled, and the material composing it uniformly spread over the whole surface of Europe, it would form a stratum only 21⅓ feet thick.

196. **Average height of continents.**—Baron Humboldt, by an elaborate calculation, obtained a pretty exact estimate of the average height of the surface of the land, composing the principal divisions of the world above the level of the sea. He found that the average height of the land in Europe is 670 feet. In North America, 748 feet. In Asia, 1132 feet; and in South America, 1151 feet.

These results demonstrate that the land in the southern regions is more elevated than in the northern. In Asia the low elevation of the extensive plains or steppes of Siberia, is compensated by the mountain masses between the parallels of 28½° and 40° lat., extending from the Himalaya to the Kuenlun of Northern Thibet, and to the Tianschian or Celestial Mountains. Some idea may be formed from these calculations in what parts of the globe the action of subterranean plutonic forces, as manifested in the upheaval of continental masses, has been most intense.

197. **New mountain ranges possible.**—"There is no sufficient reason," observes Humboldt, "why we should assume that the subterranean forces may not, in ages to come, add new systems of mountains to those which already exist, and of which Elie de Beaumont has studied the directions and relative epochs. Why should we suppose the crust of the earth to be no longer subject to the agency, which has formed the ridges now perceived on its surface? Since Mont Blanc, and Monte Rosa, Sorata, Illimani, and Chimborazo, the colossal summits of the Alps and the Andes are considered to be amongst the most recent elevations, we are by no means at liberty to assume that the upheaving forces have been subject to progressive diminution. On the contrary, all geological phenomena indicate alternate periods of activity and repose; the quiet which we now enjoy is only apparent; the tremblings which still shake the surface in every latitude, and in every species of rock—the progressive elevation of Sweden, and the appearance of new islands of eruption—are far from giving us reason to suppose that our planet has reached a period of entire and final repose."

THE OCEAN.

198. **Greatest depth.**—While the aerial ocean invests the entire surface of the globe, having a depth of from forty to fifty miles, the liquid ocean under it, as already explained, covers only about three-fourths of the solid surface, being deposited according to the laws of gravitation, in the lowest parts. According to the result of soundings, already explained, the character of the solid surface

which it covers is quite analogous to that which rises above its surface, being similarly varied by hill and valley, mountain and plain. The greatest depth of the ocean is still undiscovered. The plumb-line, in one part of the Pacific Ocean, was let down to the depth of 27600 feet by Sir James Ross without finding bottom. It has been generally assumed, as most probable, that the greatest depth of the ocean does not differ much from the greatest elevation of the land above its surface, which being in round numbers five

V.—THE SPANISH PENINSULA.

miles, would show that the extreme difference of level of the solid surface of the globe does not exceed ten miles, or about the 800th part of its diameter.

199. **Uses of the ocean.**—The vast collection of water forming the ocean ministers in an infinite variety of ways to the maintenance of the organised world, and in none more so than in its property of evaporation. It may be considered in a certain sense as a vast apparatus of distillation, by which fresh water is supplied in regulated quantity and suitable quality to all parts of the land, and in these phenomena the mountains play a conspicuous part.

200. **General system of evaporation and condensation.**—It is demonstrated in physics that when an aqueous solution is exposed to the atmosphere, the pure water which forms the chief

part of it will be converted into vapour at the surface in contact with the air; and the rate of such evaporation, other things being the same, will be proportionate to the extent of the surface, the temperature of the air in contact with it, and the superficial temperature of the solution.

The water of the ocean is a solution of certain salts and alkaline substances. The evaporation which takes place from its surface affects only the pure water, leaving the saline and other similar constituents still dissolved in it. The pure aqueous vapour thus taken into the atmosphere, rising to the more elevated strata, is transported by atmospheric currents, and attracted by the mountain summits and other elevated parts of the land, upon which it is precipitated in the form of rain or snow, from which streams flow down the declivities, discharging the functions of irrigation, and thus contributing to the maintenance of animal and vegetable life upon the land.

201. **Climatic effects.**—Independently of the obvious advantages which the ocean affords, as supplying the means of intercommunication by commerce between distant parts of the earth, it also serves an infinite variety of purposes in the climatic economy of the globe. It has been already shown that from the uniformity of its physical qualities, it has a tendency to equalise and regularise climate, so as to bring the isothermal lines into closer proximity with the parallels of latitude.

202. **Ocean currents.**—Its liquid properties, however, combined with the effects of temperature, render it further subservient to the general equalisation of the temperatures of the extreme zones, moderating the heat of the torrid and the cold of the frigid. This is accomplished by the great ocean currents, the existence, directions, and limits of which have been ascertained by modern navigators.

These currents are classed as constant, periodical, and variable, the two latter classes being determined chiefly by the influence of the winds and tides.

203. **Antarctic drift current.**—The constant currents which are by far the most important, have their origin chiefly in the southern frigid zone, from which a vast stream called the *antarctic drift current*, pours its cold waters first northwards into the Pacific and then eastwards towards the eastern coast of South America. Striking upon the shores of Chili, opposite the island of Juan Fernandez, it is diverted to the north, following the coast of the South American continent, until it encounters the jutting shores of Peru, by which it is turned westward, where it takes the name of the equatorial current.

204. **Its equatorial course.**—From that point, following the

direction of the line westward, and passing among the islands of the Indian Archipelago, it traverses the Indian ocean, and sweeping round the Cape of Good Hope, turns northwards along the west coast of Africa, until it encounters the shores of the Gulf of Guinea, which again divert it westward, where it resumes the name of the equatorial current. Traversing the Atlantic, it arrives at the northern coast of South America, and enters the Caribbean Sea through the chain of the West India islands, from which it arrives in the Gulf of Mexico.

205. **Gulf stream.**—In this long course, after cooling the waters of the tropical ocean, its own temperature is at length raised to a high point, and in that thermal state it arrives in the Gulf of Mexico. The direction of the current is there changed by the southern coast of North America, and it issues through the channel between Cuba and Florida, flowing northward along the coast of the United States, and about the 35th degree of latitude turning north-east, it again traverses the Atlantic, dividing its course into two branches, one directed between the British Isles and Iceland to Spitzbergen in the Arctic ocean, and the other by the Azores and Madeira back to the coast of Morocco.

At the point where it issues from the Gulf of Mexico, the current takes the well-known denomination of the *Gulf stream.* Its temperature, as just stated, is so elevated that its existence can readily be determined by navigators by means of the thermometer. It becomes thus a means of transporting to the regions of the northern frigid zone a portion of the tropical heat, so as to produce the equalising effect already mentioned.

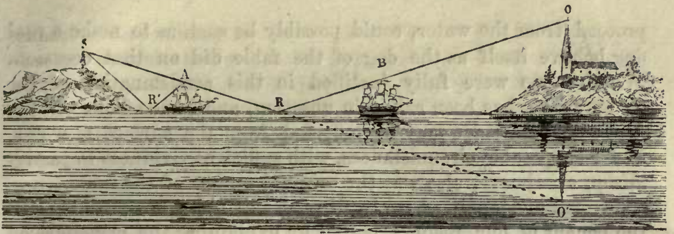
206. **Course and limits of ocean currents evident.**—" The currents of the ocean," observes Humboldt, " present a remarkable spectacle, maintaining a nearly constant breadth. They cross the sea in different directions, like rivers of which the adjacent undisturbed masses of water form the banks. The line of demarcation between the parts in motion, and those in repose, is most strikingly shown in places where long bands of sea-weeds, borne onward by the current, enable us to estimate its velocity. Analogous phenomena are sometimes presented to our notice in the lower strata of the atmosphere, when, after a violent storm, the path of a limited aerial current may be traced through the forest by long lanes of overthrown trees, whilst those on either side remain unscathed."

207. **Ocean rich in animal life.**—Although the surface of the ocean is less rich in animal and vegetable forms than that of continents, yet when its depths are searched, perhaps no other portion of our planet presents such fullness of organic life. Charles Darwin, in the agreeable journal of his extensive voyages,

justly remarks, that our land forests do not harbour so many animals as the low wooded regions of the ocean, where the sea-weed rooted to shoals, or long branches of fuci detached by the force of the waves or currents, and swimming free, upborne by air-cells, unfold their delicate foliage. The application of the microscope still further increases our impression of the profusion of organic life which pervades the recesses of the ocean, since throughout its mass we find animal existence, and at depths exceeding the height of our loftiest mountain chains, the strata of water are alive with polygastric worms, cyclidiæ, and ophrydinæ. Here swarm countless hosts of minute luminiferous animals, mammalia, crustacea, peridinea, and ciliated nereides, which, when attracted to the surface by particular conditions of the weather, convert every wave into a crest of light. The abundance of these minute creatures, and of the animal matter supplied by their rapid decomposition, is such, that the sea water itself becomes a nutritious fluid to many of the larger inhabitants of the ocean.

208. **Moral impressions.**—If all this richness and variety of animal life, containing some highly organised and beautiful forms, is well fitted to afford not only an interesting study, but also a pleasing excitement to the fancy; the imagination is yet more deeply moved, by the impressions of the boundless and immeasurable which every sea voyage affords. He who awakened to the inward exercise of thought, delights to build up an inner world in his own spirit, fills the wide horizon of the open sea with the sublime image of the Infinite; his eye dwells especially on the distant sea line, where air and water join, and where stars rise and set in ever renewed alternations: in such contemplations there mingles as with all human joy, "a breath of sadness and of longing." *

* Humbolt's Cosmos, pp. 299, 303.



SCIENCE AND POETRY.

1. Optical error in the fable of the Dog and the Shadow.—2. Explanation of the phenomena.—3. Table showing the reflection at different obliquities.—4. Effect of looking down in still water over the bulwark of a ship or boat.—5. Effect of the varying distance of the observers.—6. Experiments with a basin of water.—7. Explanation of their effects.—8. Scientific errors in Moore's Irish melody, "Oh, had we some bright little isle."—9. Demonstration of the physical impossibility of what the poet supposes.—10. Allusion in Moore's Irish melody, "Thus when the lamp that lighted," explained.—11. Allusion in Moore's melody, "While gazing on the moon's light."—12. Shakspeare's allusion to the cricket.—13. Moore's allusion to the glowworm.—14. Shakspeare on the economy of the bee.—15. Error of the phrase "blind as a beetle."—16. Lines from Campbell's "Pleasures of Hope."—17. Error of the allusions to the foresight of the ant—Lines from Prior.—18. Verses from the Proverbs.—19. Celebrated description of the war-horse in Job.—20. Unmeaning language of the translation.—21. Examination of the true meaning of the original Hebrew by Dr. McCaul and Professor Marks.—22. Interpretation by Gesenius.—23. By Ewald.—24. By Schultens.—25. Correct meaning explained.

1. In a former Tract we observed, that although the illustrations and images drawn by poets from physical phenomena are generally just and true, yet this is not always the case. They are sometimes altogether at variance with the principles of physics, and involve suppositions totally incompatible with the laws of Nature. The fable of the Dog and the Shadow, which has been handed down through so many ages, diffused through so many languages, and taught so universally in the nursery and in the school, was given as an example of this.*

It was there stated, that this popular fable involved an optical blunder, inasmuch as no reflection which could be supposed to

* See vol. vii., p. 91.

proceed from the water, could possibly be such as to make a real dog behave itself as the dog of the fable did on that occasion. Whether we were fully justified in this condemnation of the ancient fable has been called in question, and some of our readers think that an image may be reflected from the surface of water, under supposable circumstances, with sufficient vividness to justify Æsop, or whoever else was the original author of the fable.

Instead of stopping here to dispute this point, we shall consult the benefit of our readers better by explaining the principles on which it depends, and indicating some simple experiments which we have ourselves tried, and which any of our readers may easily repeat.

2. When light falls upon a plane reflecting surface, the proportion of the rays which are reflected is found by observation to be less and less, the more perpendicularly the rays are incident. The actual proportion reflected at different degrees of obliquity, was determined by Bouguer, for different substances. The results obtained by him in the cases of water and glass are given in the following table, where the angle of incidence means the angle which the incident ray makes with the perpendicular to the reflecting surface. In the fourth column of the table is given for each degree of obliquity the number of rays out of every thousand which are reflected, and in the fifth column, the number which are absorbed.

3. TABLE, *showing the proportion of Light incident on reflecting surfaces, which are regularly reflected at different angles of incidence.*

Specimen of reflecting Surface.	Angle of Incidence.	No. of Rays incident.	No. of Rays regularly reflected.	No. of Rays irregularly reflected and absorbed.
Water	89° 30′	1000	721	279
	75 0′	1000	211	789
	60	1000	65	935
	30 to 0°	1000	18	982
Glass	85	1000	543	457
	75	1000	300	700
	60	1000	112	888
	30 to 0°	1000	25	975

Now it appears from these results, that when a ray falls so obliquely upon the surface of water, as to make with the perpendicular to the surface an angle of 75°, and, therefore, with the surface itself an angle of 15°, nearly a fourth of all the incident rays are reflected. Hence it is that the image of the banks of a

lake or river, viewed by an observer (fig., page 193,) stationed at a considerable distance on the opposite side, are very vivid, the rays which produce vision in that case being those which fall with great obliquity on the water.

Since it appears, however, that when the angle of incidence is 60°, and, therefore, the obliquity 30°, less than a fifteenth of the entire number of incident rays are reflected by the water, the image must become fifteen times less vivid. If, therefore, the observer approach the opposite bank, as he may do in a boat, its image reflected in the water will be less and less vivid; or the same effect may be produced in some cases by taking a more elevated position, without changing his distance. Indeed this will give a more accurate result than the former, inasmuch as the change of distance of the eye of the observer from the point of reflection ought strictly to be taken into the account.

If the observer assume such a position, either by increasing his elevation or by diminishing his distance, that the angle of incidence shall be reduced to 30°, and, therefore, the obliquity to 60°, no more than eighteen rays in a thousand will reach the eye; and if the obliquity be still further diminished, the number of reflected rays will be much more inconsiderable.

Thus, by gradually diminishing the obliquity of the incident rays by the change of position of the observer, the reflected image, at first vivid, will be gradually more and more faint, until at length it will cease to be perceptible.

4. If a person look down into still water, over the bulwark of a vessel, he will not perceive any reflected image of his person; but if he lean over the gunwale of a boat, at a much less distance from the surface, he will perceive a faint reflection of his person under certain circumstances. The cause of this is easily explained.

The image formed by reflection is as far behind the reflecting surface as the object is before it, and the intensity of the light proceeding from such an image decreases in the same proportion as the square of its distance from the observer increases. When, therefore, the observer looks over the bulwark of a vessel, the distance of his face from the surface of the water being, for example, 12 feet, the distance of the image formed by reflection is 24 feet. The obliquity of the pencils which, proceeding from his face, are reflected by the water is very small, the rays being nearly perpendicular. Not more, therefore, than about two in every hundred of such rays are reflected to his eye, and these diverge from an image at 24 feet distance. The intensity of such reflected light is, therefore, insufficient to produce a sensible effect on the retina.

When the observer, looking over the gunwale of a boat, is within two feet, for example, of the water, the image produced by the reflected rays is only four feet distant. The intensity of the light is therefore greater, other things being the same, than in the former case, in the proportion of the square of 4 to the square of 24, or what is the same, in the proportion of 36 to 1.

5. But besides this, there is another circumstance to be taken into account. The rays of the pencils which, diverging from the person of the observer, are reflected by the water and received by the eye, have a greater obliquity than in the former case, in the same proportion nearly as that in which the distance of the observer from the surface of the water is diminished, and consequently according to the results given in the above table, a much greater proportion of these rays will be reflected. On both these accounts the image, which was imperceptible from the bulwark of the vessel, is often perceptible from the gunwale of the boat.

In all such observations, however, there are numerous modifying conditions which will vary the result in different cases. Thus, if the water be clear and transparent, and the bottom strongly illuminated, the light reflected from it will often predominate so much over the rays which produce the image to the observer, that this image will cease to be perceptible.

6. We have tried some simple experiments on this subject, the results of which are instructive, and which may be easily repeated by any of our readers.

Fill a basin with water, and place it near an open window, look down from a height of five feet vertically above the surface of the water. You will not perceive any trace of your own image in the water. Descend gradually towards the surface, and when your face is at about four feet above it, the faintest conceivable image of it will begin to be perceived. On approaching still closer, the image will be a little, but a very little, more perceptible, but even at the least distances the reflection will be so faint that it can only be perceived by concentrating the attention upon it.

Let the basin be now surrounded with a sheet or any other expedient, by which the light falling from the window upon the water shall be excluded, but so that your face being above the edge of the sheet shall be still illuminated. You will then perceive your reflected image with tolerable distinctness in the water, even at a distance of four or five feet above its surface, and this distinctness will be increased as the distance of your face above the surface of the water is diminished.

7. The explanation of these effects is obvious. When the water in the basin is exposed to the light of the window, the quantity of the light reflected from the bottom of the basin to the eye of

the observer predominates so much over the reflected rays which form the image of his face, that this image ceases to be sensible; but when by surrounding the basin with a sheet or cloth, all light proceeding from the window is excluded, no light arrives at the eye of the observer except the rays which form the image of his face, which image is therefore distinctly perceivable.

The basin of water may also be instructively applied to illustrate experimentally the results consigned to the above table by Bouguer. If it be placed on the floor or table between the observer and the window, the observer standing at a considerable distance from the basin, the rays proceeding from the window will be strongly reflected from the surface, and a vivid image of the window will be perceived in the usual inverted position in the water. As the observer approaches it, the basin at the same time being moved nearer to the window, the obliquity of the incident rays to the surface of the water is gradually diminished, and the vividness of the image will be found to decrease in a much more rapid proportion, until at length the obliquity is so far diminished that the image becomes altogether insensible.

Whether a reflection under any supposable conditions sufficiently vivid to justify the ancient fable of the Dog and the Shadow is probable, may be questioned, and we do not quarrel with some of our readers who affirm this. We admit that the expressions used by us in paragraph 18, p. 91, vol. 7, may have been too strong if they are understood to imply that in no supposable case could any image whatever be perceivable. We think nevertheless that a dog, looking into a pond with meat in his mouth, the surface of the pond being necessarily exposed to the broad light of day, would not be likely to mistake the exceedingly faint reflection of the meat for another and preferable piece of that aliment.

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8. In one of his Irish Melodies, so familiar to all lovers of poetry and music, Moore has the following lines —

"Oh! had we some bright little isle of our own,
In a blue summer ocean far off and alone,
Where a leaf never dies in the still blooming bowers,
And the bee banquets on through a whole year of flowers;
  Where the sun loves to pause
    With so fond a delay,
  That the night only draws
    A thin veil o'er the day;
Where simply to feel that we breathe, that we live,
Is worth the best joys that life elsewhere can give."

Now this is good poetry, but bad science. An "isle" in which "a leaf never dies," and in which the flowers bloom through the

year, must necessarily be within the tropics: a latitude to which the succeeding lines about the "fond delay" of the sun, and the night which only "draws a thin veil o'er the day," which produces, in other words, only a few hours of twilight, are utterly inapplicable.

9. In tropical latitudes the variation of the length of the day is very inconsiderable. It is a little more or a little less than twelve hours, and that is all. The night is, consequently, subject to a variation similarly limited. Instead therefore of the very long days and the very short nights which the poet ascribes to his "isle" in the blue summer ocean, there would necessarily be nights, the duration of which could never be much less than twelve hours in any part of the year.

But this is not all. Instead of enjoying a constant nocturnal twilight, so beautifully described by the poet as a veil drawn over the day, the inhabitants of the tropics enjoy scarcely any twilight at all, being plunged in nocturnal darkness almost immediately after sunset. This arises from astronomical causes, which will be very easily understood.

Twilight is produced by the reflection of the sun's light from that part of the visible atmosphere upon which the sun continues to shine after sunset until its depression below the horizon amounts to about 18°. Now it is apparent, that the more nearly perpendicular to the horizon the diurnal motion of the sun is, the sooner will its orb attain this depression of 18°. In the higher latitudes, where the celestial pole is not very far removed from the zenith, the sun is carried round in a diurnal circle, making a very oblique angle with the horizon; consequently, after it sets, its depression below the horizon increases very slowly, and a long interval elapses before the depression amounts to 18°. In some latitudes at the season of Midsummer it is not so much as 18° even at midnight; and in such places the poet might very truly say,—

> "The night only draws
> A thin veil o'er the day."

But the latitudes in which this can take place are very different indeed from those in which

> "a leaf never dies in the still blooming bowers,
> And the bee banquets on through a whole year of flowers."

The distance of the celestial pole from the northern point of the horizon being always equal to the latitude of the place, as may be seen by reference to our Tract on Latitudes and Longitudes, the depression of the sun below the horizon at midnight will be found by subtracting the latitude of the place from the sun's

polar distance. Now the sun's polar distance at Midsummer is $66\frac{1}{2}°$, and in order that its depression at midnight should not exceed 18°, the latitude of the place must *at least* be equal to $66\frac{1}{2}°$, diminished by 18°, that is, $48\frac{1}{2}°$.

It follows, therefore, that an entire night of twilight can only take place at latitudes higher than $48\frac{1}{2}°$. But to produce the effect expressed by the poet, a twilight should be maintained much stronger than that characterised by the scientific sense of the term. A twilight which would be only a "thin veil drawn over the day," would be such as can be only witnessed in latitudes like those of Norway and Sweden, the northern parts of Scotland, the Orkneys, &c.

In tropical latitudes, on the contrary, the celestial pole has an altitude less than $23\frac{1}{2}°$, and the diurnal path of the sun makes with the plane of the horizon an angle greater than $66\frac{1}{2}°$. After sunset, the sun therefore descends very rapidly, and the more rapidly the nearer the place is to the line. At the line itself the sun attains the depression of 18° in about seventy-two minutes after sunset; and although the twilight in the scientific sense of the term would not terminate till then, it comes to a close much sooner in the poetic sense of the "veil drawn o'er the day." In short, an almost sudden darkness succeeds sunset, and, in like manner, sunrise succeeds as suddenly to the darkness of night.

In a word, the poet, in the beautiful lines cited above, has combined incompatible astronomical and climatological conditions. The perpetual summer necessarily infers tropical latitude, while the short and twilighted night infers a high, not to say a polar latitude.

It would, perhaps, be deemed hypercritical to examine how far the naturalist would justify the poet in his allusion to the industry of the bee in a tropical climate. The honey-bee, which no doubt was the insect alluded to by the poet, is, for the most part, confined to ultra-tropical latitudes. Since, however, there are certain species of this insect found in the lower latitudes, it may be admitted that the poet has, at least in this point, a *locus standi*.

Having had the pleasure of the personal acquaintance of the author of the Melodies, I once pointed out to him these scientific incompatibilities in his lines. He replied good-humouredly, that it was lucky when he wrote the song that such inconsistencies did not occur to him; for, if they had, some pretty thoughts would inevitably have been spoiled, since he could not have been brought knowingly to take such liberties with the divinities of Astronomy and Geography.

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10. The allusion and imagery which Moore loved to seek in certain parts of physical science were generally much more

consistent with physical truth, without being less beautiful, than that which we have quoted above.

How happily, for example, did he avail himself of that beautiful property of the iris by which it accommodates the eye to greater and less degrees of light, enlarging the pupil when the light is faint, and contracting it when it is intense.

The iris, as is well known, is the coloured ring which surrounds the dark spot in the middle of the eye; this dark spot being not a black substance, but a circular orifice through which the light is admitted to the membrane lining the posterior part of the internal chamber of the eye. This circular orifice is called the pupil, the retina being the nervous membrane which produces the visual perceptions. These, with other particulars of the structure of the eye, will be found fully explained in our Tract on that subject.

The iris which surrounds the pupil has a certain power of contraction and expansion, which is produced by the action upon it of proper muscles provided for that purpose.

The quantity of light admitted through the pupil to the retina is increased or diminished in the proportion of the area of the pupil, which increases and diminishes in proportion to the square of its diameter; a very small variation of which therefore produces a very considerable proportionate variation of the quantity of light admitted.

If a person, after remaining for some time in a room dimly lighted, pass suddenly into one which is strongly illuminated, he will become instantly sensible of pain in the retina, and will involuntarily close his eyes. After a short time, however, he will be enabled to open them and look around with impunity.

The cause of this is easily explained. In the dimly lighted room the pupil was widely expanded to collect the largest quantity possible of the faint light, so that a sufficient quantity might be received by the retina to produce a sensible perception of the surrounding objects. On passing into the strongly illuminated room the expanded pupil admits so much of the intense light as to act painfully on the retina, before there is time for the iris to adjust itself so as to contract the aperture of the pupil. After a short interval, however, this adjustment is made, and the area of the pupil being diminished in the same proportion as the intensity of the light to which it is exposed, has been augmented in passing from the one room to the other, the action upon the retina is proportionally mitigated, so that the eye can regard without pain the surrounding objects.

The reverse of all this takes place when the eye suddenly passes from strong to feeble illumination. The pupil contracted

when exposed to the strong light is not sufficiently open to admit the rays of feeble light necessary to produce visual perception, and for some time the surrounding objects are invisible. When, however, the proper muscular apparatus has had time to act upon the iris so as to enlarge the pupil, the rays are admitted in greater quantity, and the surrounding objects begin to be perceived. These phenomena are beautifully expressed by the lines of Moore:—

"Thus when the lamp that lighted
The traveller, at first goes out,
He feels awhile benighted,
And lingers on in fear and doubt;

"But soon the prospect clearing,
In cloudless starlight on he treads,
And finds no lamp so cheering
As that light which Heaven sheds."

Nevertheless there is a point in this which demands some explanation. It is implied in these lines that the source of nocturnal illumination is chiefly, if not exclusively, *starlight*. This has been in a great measure disproved in some memoirs published by Arago in the "Annuaire du Bureau des Longitudes," in which he shows that there must be some other source of nocturnal illumination than that of the stars. On nights, for example, which are thickly clouded there is sometimes a stronger light than on those in which the firmament is clear and serene. From this and other circumstances Arago argues that there must be some power of illumination in the clouds or in the atmosphere independently of the light which proceeds from the stars. This is a point, however, the full development of which would require more space and time than we can spare for it on the present occasion.

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11. In another of Moore's poems we find the following beautiful lines:—

"While gazing on the moon's light
A moment from her smile I turn'd,
To look at orbs that, more bright,
In lone and distant glory burn'd.
But too far
Each proud star,
For me to feel its warming flame,
Much more dear,
That mild sphere,
Which near our planet smiling came.
* * * *
Thus, Mary, be but thou my own;
While brighter eyes unheeded play,
I'll love those moonlight looks alone,
That bless my home and guide my way."

This is not only beautiful poetry, but sound astronomy. The distances of the stars are many hundreds of millions of times greater than that of the moon, but their actual splendour is in many cases greater than that of the sun. Thus it has been shown by calculations made upon observations which appear to admit of no doubt, that the star Sirius, commonly called the Dog-star, is a sun 146½ times more splendid than that which illuminates our system. Its distance, however, is so enormous that the actual light which it sheds upon our firmament is less than the five thousand millionth part of the sun's light.

Another star, which is the principal one in the constellation of the Centaur, has been ascertained to be a sun whose splendour is 2⅓ times greater than that of ours, but owing to its enormous distance the light which it sheds in our firmament is twenty-two thousand million times less than that of the sun.*

Sir John Herschel compared the light shed by this star from our firmament, and found by exact photometric measurement that it was 27408 times less than the light of the full moon.

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12. Shakspeare imputes to the cricket the sense of hearing—

"I will tell it softly, young crickets shall not hear me.

This was long considered as a scientific blunder on the part of the poet, the most eminent naturalists having maintained that insects in general have no sense of hearing. Brunelli, an Italian naturalist, however, has demonstrated that the cricket at least has that sense. Several of these insects, which he shut up in a chamber, continued their usual crinking or chirping the whole day except at moments when he alarmed them by suddenly knocking at the door. The noise always produced a temporary silence on their part. He contrived to imitate their sounds so well that the whole party responded in a chorus, but were instantly silenced on his knocking at the door.

He also made the following experiment. He confined a male cricket on one side of his garden, while he put a female on the other side at liberty. The moment the belle heard the crink of her beau she showed no coyness, but immediately made her way to him.

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13. The female glowworm, which emits the phosphorescent light, familiar to all who have dwelt in warm climates, remains comparatively stationary to await the approach of her mate, attracted

* Lardner's Astronomy, pp. 749, 752.

to her by the light which she holds out to him, a circumstance of which Moore has availed himself with his usual felicity:—

> "Beautiful as is the light
> The glowworm hangs out to allure
> Her mate to her green bower at night."

14. The well-known economy of the bee was never more beautifully described than by Shakspeare, who puts the following comparison into the mouth of the Archbishop of Canterbury:

> "True! therefore doth Heaven divide
> The state of man in divers functions,
> Setting endeavour in continual motion;
> To which is fixed, as an aim or butt,
> Obedience: for so work the honey bees;
> Creatures that, by a rule in nature, teach
> The act of order to a peopled kingdom.
> They have a king, and officers of sorts:
> Where some, like magistrates, correct at home;
> Others, like merchants, venture trade abroad;
> Others, like soldiers armed in their stings,
> Make boot upon the summer's velvet buds;
> Which pillage they with merry march bring home
> To the tent royal of their emperor!
> Who, busied in his majesty, surveys
> The singing masons building roofs of gold;
> The civil citizens kneading up the honey;
> The poor mechanic porters crowding in
> Their heavy burdens at his narrow gate;
> The sad-eyed justice, with his surly hum,
> Delivering o'er to éxecutors pale
> The lazy yawning drone."
>
> *Henry V.*, Act. I., Scene 2.

15. The phrase "as blind as a beetle," is as false as it is familiar. In the rapid flight of this insect in the evenings of summer, it often strikes the face of those who walk abroad, and hence is erroneously inferred to be blind.

Collins describes this insect in the well-known lines of his Ode to Evening:—

> "Now air is hushed, save where
> The beetle winds his small but sullen horn,
> As oft he rises midst the twilight path,
> Against the pilgrim borne in heedless hum."

The poet, it will be observed, avoids falling into the popular error of imputing blindness to the insect.

16. In Campbell's immortal poem, the Pleasures of Hope, we find the following lines :—

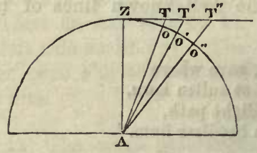
> "Angel of Life! thy glittering wings explore
> Earth's loneliest bounds, and Ocean's wildest shore.
> Lo! to the wintry winds the pilot yields
> His bark careering o'er unfathom'd fields;
> Now on Atlantic waves he rides afar,
> Where Andes, giant of the western star,
> With meteor standard to the winds unfurl'd,
> Looks from his throne of clouds o'er half the world."

Although it is difficult to assign a limit to the degree of exaggeration allowed by the licence of poetry, it is quite clear that there is some such limit, and we apprehend that if these lines, so admirable as poetry, be curiously examined by the light of science, they will scarcely be considered as falling within such limit.

We are to imagine with the poet the genius of the Andes enthroned upon the most lofty peak of that chain, looking round him at the hemisphere, on the middle of which his throne rests. To behold from such a position "half the world," would be a manifest optical impossibility, however elevated his seat might be. But if his range of view could in any degree approximate to half, or even to a quarter of the globe, the exaggeration might be allowed to pass. Let us see, however, what would be the utmost possible range of view which could be obtained by an observer placed upon the apex of the most lofty cone of the Andes, supposing the surrounding mountains of less elevation not to interrupt his general view of the earth's surface.

The most lofty peak of the Andes is that of Aconcagua, which rises immediately above Valparaiso, overlooking the Pacific Ocean. The extreme height of this summit is 23910 feet. Now let us see what would be the extreme range of view from such an elevation; and in making this calculation we shall, contrary to our custom, introduce its mathematical details, so as to inspire our readers with greater confidence in the result. Let us suppose the semicircle here indicated to represent the section of the hemisphere, near the middle of which the summit of the mountain is placed. Let O represent the base, and T the summit of the mountain. If a line T Z be drawn touching the earth, the point Z will be the limit of the range of view of an observer looking from T in the direction of T Z, and the

Fig. 1.



terrestrial arc Z O will therefore represent the radius of the circle round the observer, which will be seen visible to him. In short, it will represent his terrestrial horizon, which the poet in the lines quoted assumes to be half the globe. By calculating the arc Z O, the degree of exaggeration in the poetical illusion will be rendered apparent.

The height of the peak of Aconcagua, reduced to geographical miles, is 3·935. The length, A Z, of the earth's semi-diameter, also expressed in geographical miles, is 3438, and, consequently, of the line A T will be $3438 + 3{\cdot}935 = 3441{\cdot}935$. Let the terrestrial arc Z O be expressed by A, we shall then have

$$\text{Cos. A} = \frac{\text{A Z}}{\text{A T}} = \frac{3438000}{3441935}$$

To compute the value of A, we shall have, therefore—

$$\begin{aligned} \text{Log. } 3438000 &= 6.5363059 \\ \text{Log. } 3441935 &= 6{\cdot}5368021 \\ \hline \text{Log. Cos. A} &= 9{\cdot}9995038 \\ \hline \text{A} = 2^\circ\, 44'\, 18'' &= 164{\cdot}3 \text{ miles.} \end{aligned}$$

It appears, therefore, that the range of view round such an observer would be confined within a radius of 164 geographical miles, whereas "half the world," supposing it to be spread out in a circle under the eye of the observer, would be measured by a radius of 90×60, or 5400 miles, so that half the world would be measured by a radius more than thirty-two times that which would actually limit the view of Campbell's "giant of the western star." We admit, however, that the task is rather an ungracious one, which consists in thus cutting down the splendid imagery of Campbell's poetry to the level of the severe limits of scientific truth, and if we do so, it is more for the sake of exercising our readers in physical enquiry, and habituating them to mathematical precision, than with any intention of depreciating poetic beauties of which we are as sensible as others.

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17. No notion is more prevalent, respecting the insect economy, nor more frequently embodied in the imagery of poets and in the eloquence of moralists, than the industry and foresight imputed to the ant:—

—"Tell me, why the ant,
'Midst summer's plenty, thinks of winter's want,
By constant journies careful to prepare
Her stores, and, bringing home the corny ear,

> By what instruction does she bite the grain,
> Lest, hid in earth, and taking root again,
> It might elude the foresight of her care ?"
>
> PRIOR.

It has been ascertained, however, that these instincts are erroneously imputed to the ant. That insect passes the winter in a torpid state, and does not lay up any store of provisions. Still less does it take any such precautions as those commonly imputed to it, of biting off the ends of the grains which it lays in store, to prevent them from germinating. It is supposed that this error may have arisen from the insect being observed to carry about their young in the pupa state, in which they have some resemblance to a grain of corn, and also from their being observed to gnaw off the end of the sheath which encloses the pupa, in order to liberate the insect, after it has attained its perfect state, from its confinement.

18. The words of Solomon respecting this insect, which occur in Proverbs, vi. 6, 7, 8, are well known :—

> 6. Go to the ant, thou sluggard ; consider her ways and be wise.
> 7. Which having no guide, overseer, or ruler,
> 8. Provideth her meat in the summer, *and* gathereth her food in the harvest.

If the original Hebrew word, which has been here translated by the Saxon ant, properly signifies the European insect of that name, these verses of Solomon would undoubtedly involve an error in zoological history ; but that cannot be affirmed until the habits and manners of other species of the insect inhabiting warmer climates have been examined and ascertained. For although during the cold winters incidental to this climate, the ants remaining in a torpid state do not need food, yet in warmer regions, where they are probably confined to their nests during the rainy season, a store of provisions may be necessary for them. This supposition has been to a great extent verified by the discovery made by Colonel Sykes, at Poonah, in India, of a species of ant, which he denominates *Atta providens*, which store up the seeds of a kind of grass called *panicum*, at the time they are ripe in January and February, which they expose on the outside of their nests to the sun in the warm season, for the purpose of drying them after they have been wetted by the rains of the Monsoon. Such measures cannot be explained, except by the supposition that these seeds are destined for food, and though there is no recorded instance of ants feeding on any vegetable substances, except such as are saccharine, yet, all experience proves how constantly in entomology, exceptions to general laws

are presented, and there seems to be good reason to believe that this is one of them.*

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19. Every reader who is duly sensible of the sublime poetry of certain parts of the Hebrew Scriptures will be familiar with the following splendid description of the war-horse in the Book of Job, xxxix. 19:—

19. Hast thou given the horse strength? hast thou clothed his neck with thunder?

20. Canst thou make him afraid as a grasshopper? the glory of his nostrils *is* terrible.

21. He paweth in the valley, and rejoiceth in his strength: he goeth on to meet the armed men.

22. He mocketh at fear, and is not affrighted; neither turneth he back from the sword.

23. The quiver rattleth against him, the glittering spear and the shield.

24. He swalloweth the ground with fierceness and rage; neither believeth he that *it is* the sound of the trumpet.

52. He saith among the trumpets, Ha, ha; and he smelleth the battle afar off, the thunder of the captains, and the shouting.

20. In reading these verses, one is so dazzled with their splendour that it is difficult to submit them to the cold test of physical truth. Nevertheless, it has always appeared to us, that the second member of the first verse above quoted is, as translated, destitute of all meaning. To clothe an object with thunder would be to clothe it with a sound, which obviously is destitute of all meaning either literal or metaphorical. It might seem as though the allusion intended in the original of the passage might have been to lightning and not to thunder. One can conceive the waving and flashing of the mane of the war-horse fairly enough imaged by lightning, especially when considered in connection with the roar of the battle-field and "the thunder of the captains," so finely described in a succeeding verse. If the original Hebrew term which has been translated by the word thunder could bear the signification of lightning, the objection here advanced would be removed.

To say that a thing is clothed with a sound reminds one of an anecdote to which we have alluded on a former occasion. A blind man being asked what idea he had of the colour scarlet, replied that he believed he had a very clear notion of it, for that it was just like the sound of a trumpet.

21. Thinking it highly probable that the blemish which I have

* Trans. Ent. Soc., London. Vol. ii. p. 211.

here indicated was attributable to the translators, rather than the author, of the book of Job, I have had recourse to the original Hebrew; and desiring on such a point to be supported by higher authority than I can myself lay claim to, I requested the aid of two eminent Hebraists, Dr. Alexander McCaul, of King's College, and the Rev. Professor Marks, of University College, London, both of whom have favoured me with their opinions and suggestions on the subject; and, as they do not materially differ, there can be no doubt that their interpretation is substantially correct. It appears, as I anticipated, that the translation is faulty; but, on the other hand, the Hebrew word which has been translated thunder never means lightning.

22. Gesenius says that the primitive sense of the term used is tremor, or trembling, being derived from the verb Raam, which signifies to tremble. In verse 19, he says, that it has the primary sense, tremor, and that it is used poetically for the mane of a horse, as in the Greek φόβη. Here, however, are his words from the Thesaurus:

"רַעְמָה f. 1, *tremor;* poet. pro juba equi, quæ in equis nobilioribus propter cervicis obesitatem contremiscit, unde gr. φόβη, juba, a φόβος. (Job. xxxix. 19.)"

23. The famous Ewald, the other great authority in Hebrew, in his "Poetische Bücher des Alten-Bundes," gives the same sense, and translates the word by the German Zittern, trembling. Both understand the trembling mane, and therefore find no allusion to thunder or lightning. The word is by none interpreted *lightning*, and cannot have that meaning. The LXX have φόβον, tremor, which Gesenius supposes to be equivalent to φόβη, mane. Symmachus has κλαγγήν. Theodotion, χρεμετισμόν, which sense is also given by the Vulgate, Hinnitum. The moderns, who prefer this sense, take "neck" as poetic for "throat," or explain the thunder of the sound of the long shaking mane.

24. Schultens translates the word "tremore alacri," (with rapid quivering). Parkhurst translates the word thus, "With the shaking mane."

25. On the whole, therefore, it appears that the English version of the second member of v. 19, chap. xxxix. is incorrect. "Hast thou clothed his neck with thunder?" is not the sense of the original Hebrew, which would be correctly rendered thus, "Hast thou clothed his neck with a shaking (or flowing) mane?"

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